

ENG-445

Energy and Comfort in Buildings



Introduction:

Energy concepts and fundamentals

The value of human-centric buildings

September 12, 2024



Human-Oriented Built Environment Lab

Website: hobel.epfl.ch

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EPFL

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School of Architecture, Civil and

Environmental Engineering

École polytechnique fédérale de Lausanne

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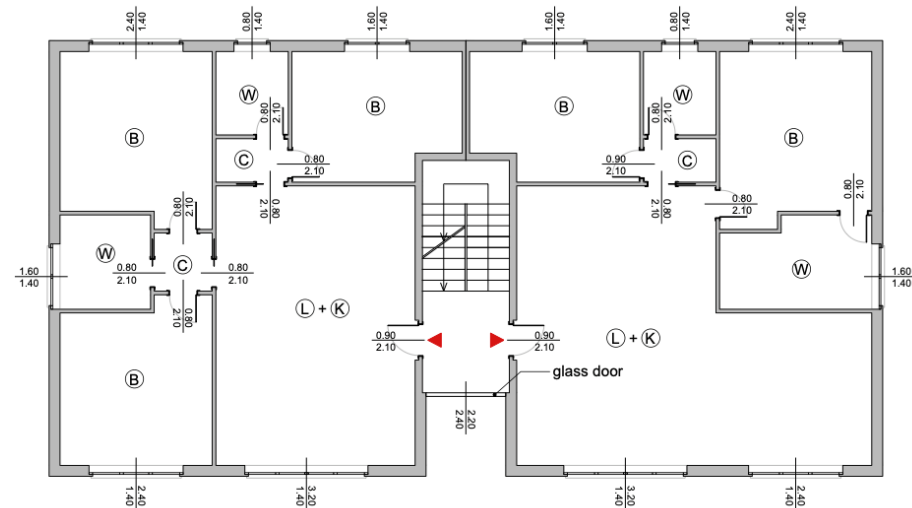
Today's learning objectives (9h15 – 12h00)

- Introduce ourselves and yourselves
- Discuss the course syllabus
 - Course information, outline, schedule, ground rules
 - Why are we all here?
- Introduce the field of building energetics
 - Energy and climate crisis
 - Energy use in buildings
- The value of human-centric buildings
 - Why does it matter?
- Quiz on climate change
- Bonus slides (on your own if needed)
 - Brush-up (units, heat transfer, psychometrics)

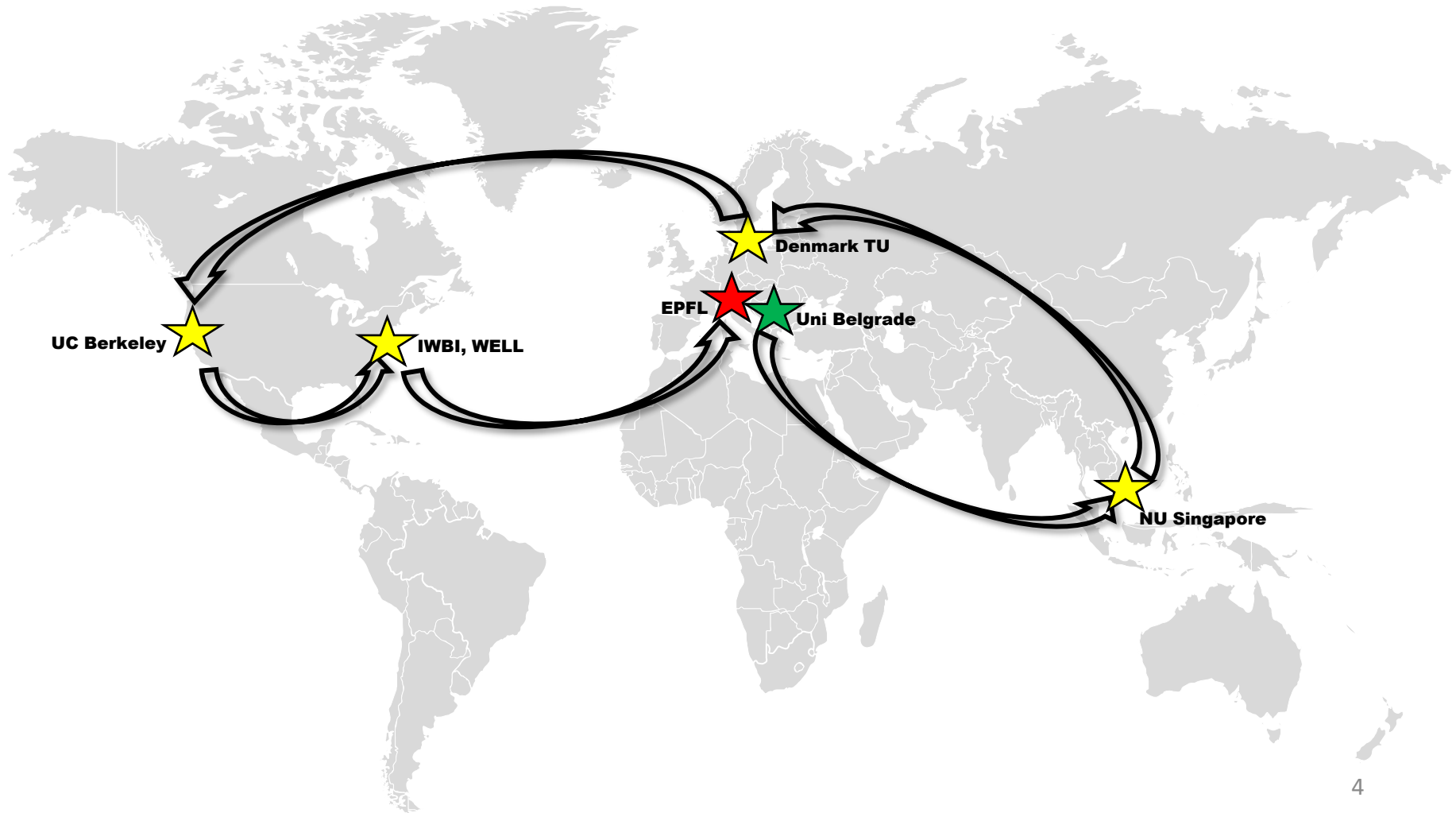
Today's project objectives (12h30 – 14h00)

- Scheduled time: Thursday 12:30-2:00 (see course schedule)
 - Tutorials some weeks
 - Free work some weeks
- Energy modeling of a building
- Part 1: individual modeling of a single apartment + energy performance strategies
- Part 2: group work on building modeling + design

Week	Date	Topic	Timing	Teacher	Project (AS)
1	12/09	Course Introduction	45'	DL	Introduction (BPS) + Start individual project + Import geometry
		Climate change and energy	45'		
		Energy use in buildings	45'		
		The value of human-centric buildings Quiz On your own: Quick recall of units, heat transfer, psychrometrics	45'		
2	19/09	Thermal comfort, quick overview	45'	DL	Free work
		Overheating of buildings	45'		
		Thermal comfort & energy efficiency	45'		
		Exercises	45'		



My carbon footprint trajectory...



Indoor air quality (IAQ)

Exposure science

Building
environmental
monitoring



Smart ventilation
systems

Indoor environment and
building energy nexus



Lausanne – Main Campus

Fribourg – Smart Living Lab

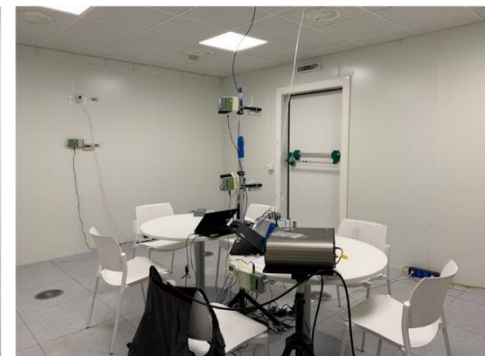
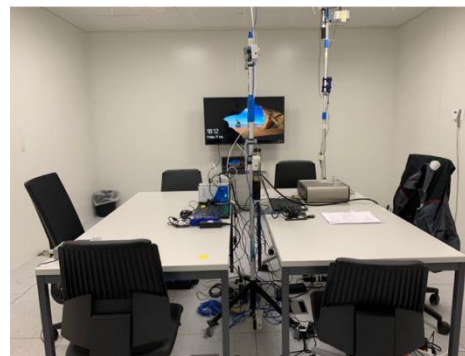
Neuchâtel – Microcity

Sion – Energypolis Campus

Geneva – Campus Biotech



Unique experimental facility



Low-cost

Medium-grade

High-grade

Available MSc / semester projects at HOBEL

Some examples:

1. The impact of real-time indoor air quality awareness on occupant behavior and ventilation rates in student dwellings
2. Indoor air quality and thermal comfort assessment at university campus building
3. Building and testing a low-cost thermal manikin
4. Performance assessment of natural ventilation in Swiss residences
5. Assessment of air quality and thermal comfort on public transport
6. Human inhalation exposure to carbon dioxide and particulate matter in built environment
7. A novel camera-based method for estimating perceived indoor air quality and environmental satisfaction
8. Calibration of an building energy simulation model based on actual data
9. Exploring the Global Thermal Comfort Database
10. Analysing building energy and indoor environmental data in a Swiss residential building

Dolaana Khovalyg



- **Assist. Professor in Energy and Building Systems Engineering at ENAC since 2018**
- **Head of the Laboratory of Integrated Comfort Engineering (ICE)**
- **Research focus:** thermal conditioning of buildings, building physics, well-being and comfort of building occupants
- **Teaching activities:**
 - *Urban Thermodynamics (CIVIL-309)*
 - *Building Energetics (ENG-445)*
 - *Thermodynamics of Comfort in Buildings (CIVIL-450)*



**Integrated
Comfort
Engineering
Laboratory**

Advancing human comfort studies and the design and control of occupant-centered buildings

- PURPOSE:**
- Promote the well-being and thermal comfort of building occupants
 - Reduce the carbon footprint of thermal conditioning in buildings

RESEARCH TOPICS:



More details on our website: <https://www.epfl.ch/labs/ice/>

Andrew Sonta



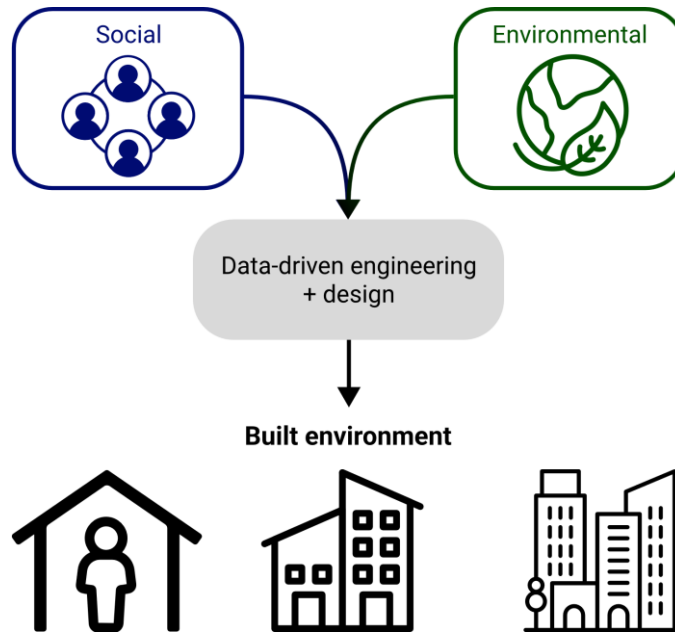
Tenure-Track Assistant
Professor
September 2022 – present

Previously:

- Postdoc, Columbia University, Data Science Institute
- PhD, Stanford University, Civil and Environmental Engineering

ETHOS Lab

Engineering and Technology for Human Oriented Sustainability



Research vision
Using **data**, **engineering**, and **design** to create interventions in the built environment that integrate our **social** and **environmental** goals.

Current projects

- Occupant-centric building design and management
- Socio-environmental analysis of urban form

Your project instructor + guest lecturer



Matteo Favero

PostDoctoral Researcher | Engineering and Technology
for Human-Oriented Sustainability (ETHOS Lab) | EPFL

Education

- BSc and MSc in Building Engineering @ **Politecnico di Milano, Italy**
- PhD in Civil and Environmental Engineering @ **NTNU, Norway**

Past research projects

- PhD Research Fellow within **WP4 Energy flexible neighbourhoods @ FME ZEN Centre**
- **IEA EBC Annex 79** on 'Occupant behaviour-centric building design and operation'

Ongoing research projects

- **Human-building interaction** and **occupant-centric models** for thermal comfort in buildings
- **IEA EBC Annex 87** on 'Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems'

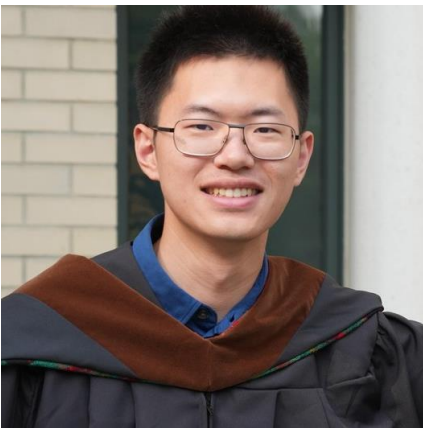
Your teaching assistants this semester...

Yufei Zhang



Yufei is a doctoral student in the ETHOS Lab. He received his MSc degree from the Integrated Building System Programme at ETH Zurich, where he studied the design and operation of urban energy systems via simulation and data-driven approaches. He obtained his BSc from Tongji University in China, also majoring in energy applications in the built environment. In his free time, he enjoys street workouts and is always fascinated by video games.

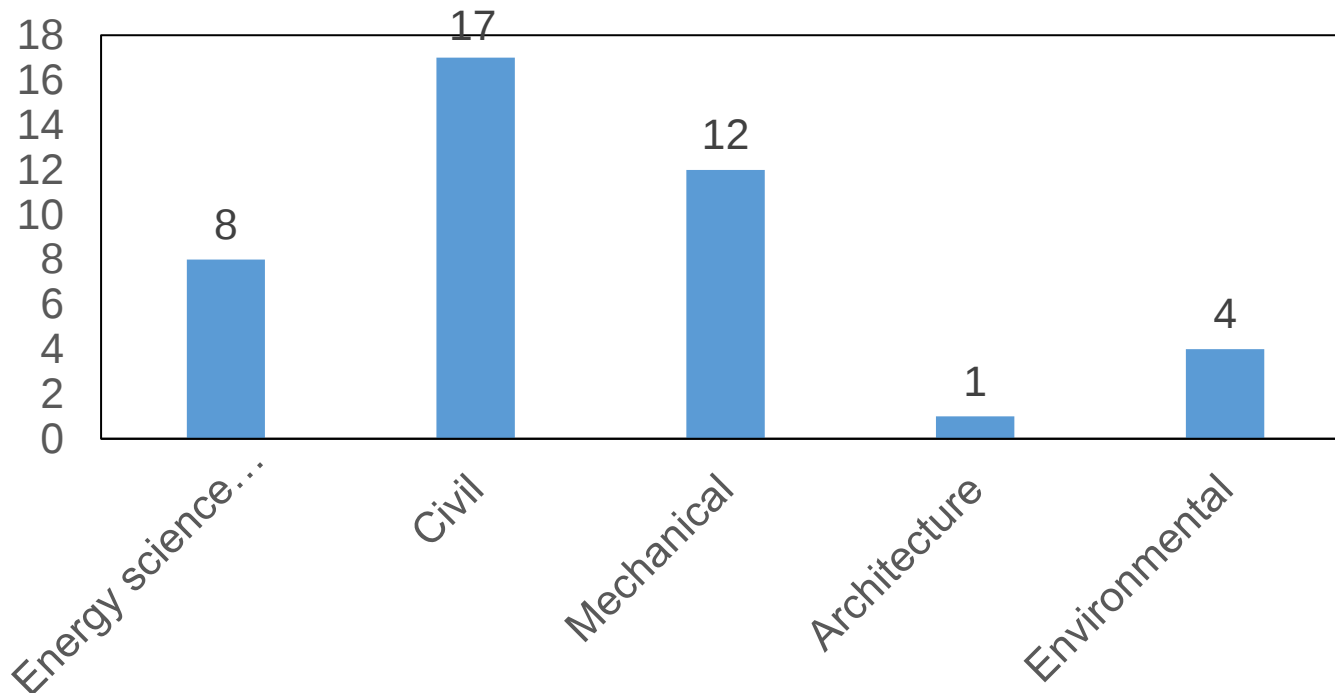
Tianqi Liu



Tianqi Liu is a doctoral student in the HOBEL lab. He received his Master of Science degree in Building Performance and Diagnostics from Carnegie Mellon University in Pittsburgh, Pennsylvania, United States (2023) and his Bachelor of Engineering degree in Building Environment and Energy from Tianjin University in Tianjin, China (2021). He is interested in optimization of sensing techniques for indoor environment and advanced HVAC controls to improve occupants' overall well-being and reduce energy consumption.

About you...

- Who are you?
 - Where are you from?
- Any relevant work and/or research experiences?
 - Any PhD students?



Course information: ENG-445

Classroom and Meeting Time

- Thursdays, 09h15 – 12h00; Room: CE1104

Office and hours – Prof. Dusan Licina

- Thursdays, 14h to 15h
- Office GC A1 354

Office and hours – Prof. Dolaana Khovalyg

- Thursdays, 14h to 15h
- Office GC A1 344

Office and hours – Prof. Andrew Sonta

- Tuesday, 14h to 15h
- Office GC G1 484

Prerequisites

- Elementary building physics
- Familiarity with heat transfer, HVAC systems, comfort and indoor climate and energy demand in buildings is a plus

Course information: ENG-445

Course Content Official Description

- Energy use in buildings
- Human-centric buildings
- Thermal comfort requirements
- IAQ and ventilation requirements
- Importance of human behavior



1st half of
semester

- Solar geometry and heat gain
- Building envelope
- Heating & cooling demand
- Heating and cooling systems
- Green building standards



2nd half of
semester

Course learning outcomes

By the end of the course, you will be able to:

- Integrate human comfort requirements into the building energy design and operation cycles
- Comprehend intersections between building energy demand, indoor environmental quality (air quality & thermal comfort) and occupants
- Comprehend the energy flows in a building and calculate the heat balance
- Learn basics of building energy simulation tools
- Become familiar with the existing green building standards

Course resources

Purchasing a textbook is **not compulsory** for this course

The reference textbooks from which we will draw information, for your consideration:

- Edward Allen. How Buildings Work: The natural Order of Architecture, 3rd ed. (*downloadable from Moodle*)
- Claude-Alain Roulet. Energétique du bâtiment - Tome 1 and 2. PPUR.
- Y. A. Çengel; A. J. Ghajar, Heat and Mass Transfer: Fundamentals and Applications. McGraw Hill Education, 5th edition
- ASHRAE Handbook of Fundamentals, 2018
- Different building standards such as ISO 17772, ISO 6946, ASHRAE 55, ASHRAE 62.1, SIA 380/1, SIA 2024.
- Peer-reviewed papers and websites – it will be provided throughout the semester.

Course deliverables and grading

• Exam 1 (1 st half of the course)	35 pts
• Exam 2 (2 nd half of the course)	35 pts
• Individual project report	15 pts
• Group project presentation	15 pts
Total	100 pts

Grading scale:

- | | |
|---------------|----------|
| • 5.50 - 6.00 | ≥ 90% |
| • 5.00 - 5.49 | 80-89.9% |
| • 4.50 - 4.99 | 70-79.9% |
| • 4.00 - 4.49 | 60-69.9% |
| • 0.00 - 3.99 | < 59.9% |

Course schedule: 1/2 (available on Moodle)

Week	Date	Topic	Timing	Teacher	Project (AS)
1	12/09	Course Introduction		DL	Introduction (BPS) + Start individual project + Import geometry
		Climate change and energy	45'		
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2	19/09	Thermal comfort, quick overview		DL	Free work
		Overheating of buildings	45'		
		Thermal comfort & energy efficiency	45'		
3	26/09	Exercises	45'	DL	Tutorial Shading +Thermal comfort + Overheating
		IAQ - Why we must care? Perceived and physical air quality	45'		
		IAQ and ventilation relationship Introduction to ventilation	45'		
4	03/10	Exercises	45'	DL	Free work
		Quiz Week 3			
		Standard ventilation requirements	45'		
		Ventilation and energy Quiz Week 4	45'		
5	10/10	Occupant behavior in buildings Influence on energy use Plug loads	45' x 2	MF (guest)	Tutorial Natural ventilation + Schedule (people, light, ...)
		Exercises	45'		
6	17/10	Written test 1 (lectures 1-5), 35 pts	100'	TBD	Free work

Course schedule: 2/2 (available on Moodle)

Week	Date	Topic	Timing	Teacher	Project (AS)
7	24/10	Fall break			
8	31/10	Heat transfer, solar geometry, solar heat gain, daylighting	45' x 2	DK	Delivery of individual report, 15 pts
		Exercises	45'		Start group project + Discussion among group members about different solutions [this is the base to start the group exercise]
9	07/11	Building envelope, thermal performance of building elements	45' x 2	DK	Tutorial building envelope
		Exercises	45'		
10	14/11	Heating and cooling demand in buildings	45' x 2	DK	Free work
		Exercises	45'		
11	21/11	Thermal systems for heating and their effect of human comfort	45' x 2	DK	Free work
		Exercises	45'		
12	28/11	Thermal systems for cooling and their effect of human comfort	45' x 2	DK	Tutorial heating systems (emission systems)
		Exercises	45'		
13	05/12	Standard and guidelines for green buildings	45'	DL	Free work
		Group debate workshop and course evaluation	45' x 2	All	
14	12/12	Written test 2 (lectures 8-13), 35 pts	100'	TBD	Free work
15	19/12	Project presentations	45' x 3	All	Delivery presentation, 15 pts

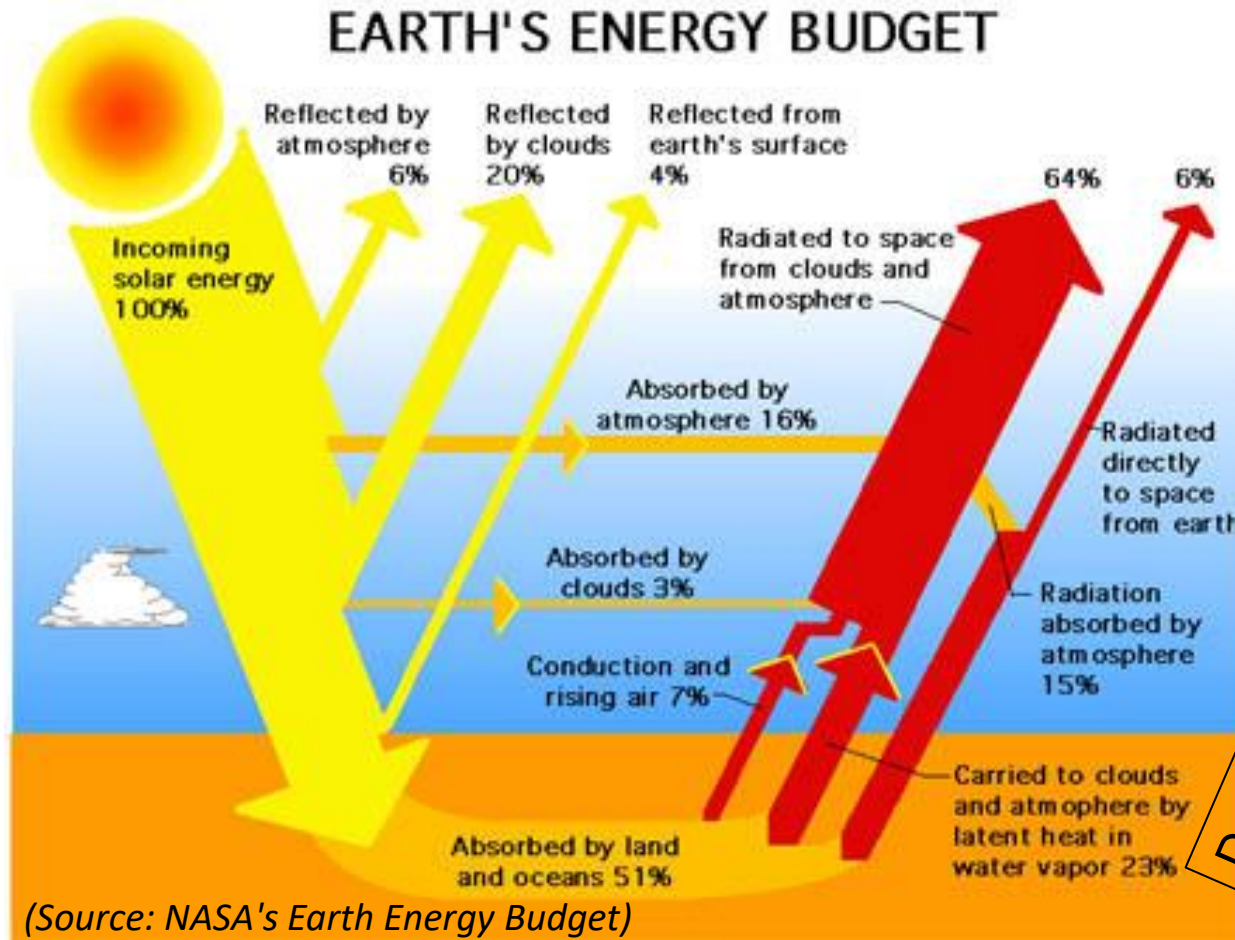
Other relevant details...

- I will post lecture notes and updated syllabus on Moodle
 - I will do so usually 1-3 days before class
- I will generally communicate with the class via email
 - Don't let me go into your spam folder
 - Do you have a different email address that you prefer?
 - If so, email me at dusan.licina@epfl.ch
- Please make sure to:
 - ask when you have a question or when you want to share a comment / experience
 - participate in discussions whenever given an opportunity
 - participate in all pooling sessions and quizzes

Any questions so far?



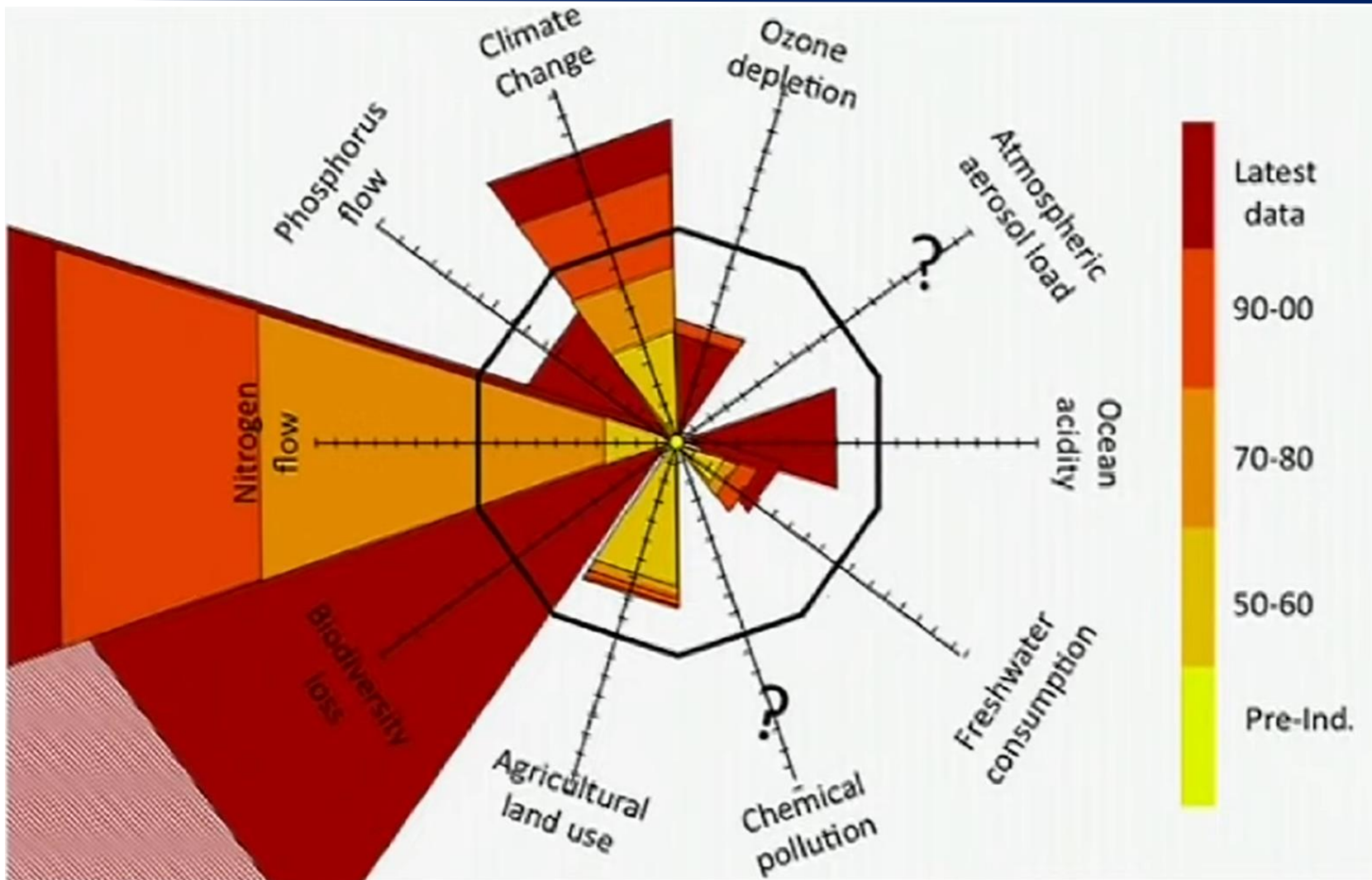
Reason behind everything: GHG



Does +1.1 °C matter?
Yes! >1 °C of fever already indicates an illness in the human body (compared to normal temperature of +37 °C)

- Without GHG: Mean global temperature would be 33 °C lower!
- Man-made GHG: Additional warming since pre-industrial time = +1.1 °C during last decade (IPCC AR6).

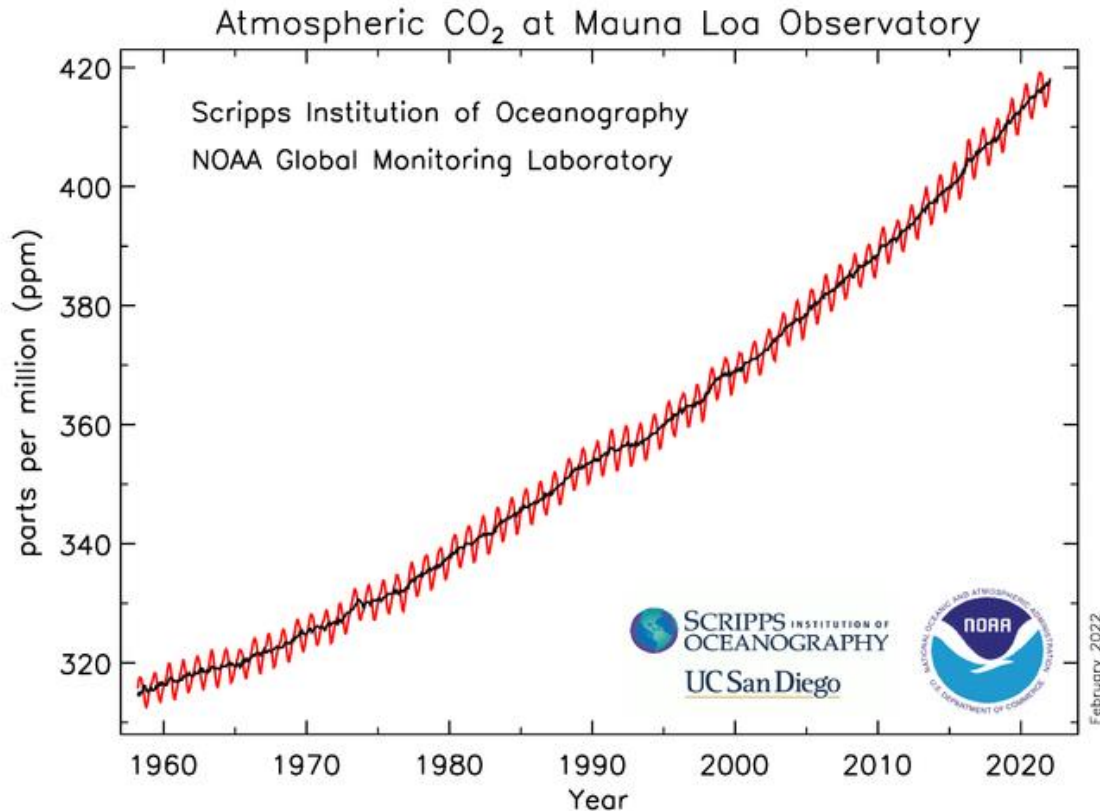
The 10 limits of our planet



(Science article: <https://www.science.org/doi/10.1126/sciadv.adh2458>)

Newspapers article: <https://ideas.ted.com/the-9-limits-of-our-planet-and-how-weve-raced-past-4-of-them/>)

Staggering facts



- The atmospheric abundance of CO₂ has risen from its pre-industrial level of **280 ppm** to a level of **420 ppm** today.
- “Planetary boundary” already exceeded (**350 ppm**).
- The CO₂ level continues to increase at a rate of a few ppm per year.

Staggering facts

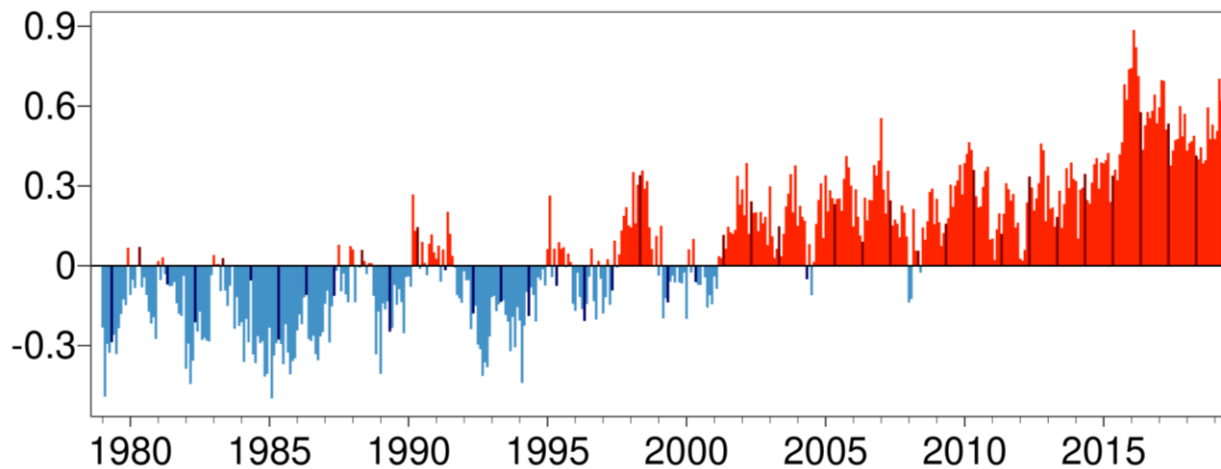
- CO₂ concentrations are increasing unabatedly no matter how much scientific information is produced, thought, shared, discussed...
- “Business as usual” trajectory will bring us to a rise in atmospheric CO₂ to **500 – 1000 ppm** by 2100!

What are the implications?

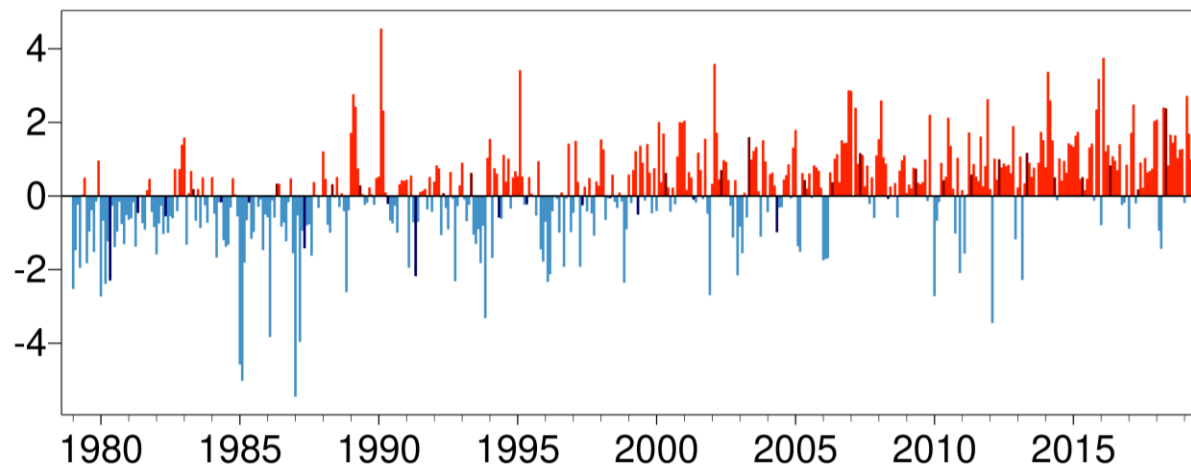
*(Source: Intergovernmental
Panel on Climate Change)*



Global surface air temperature change

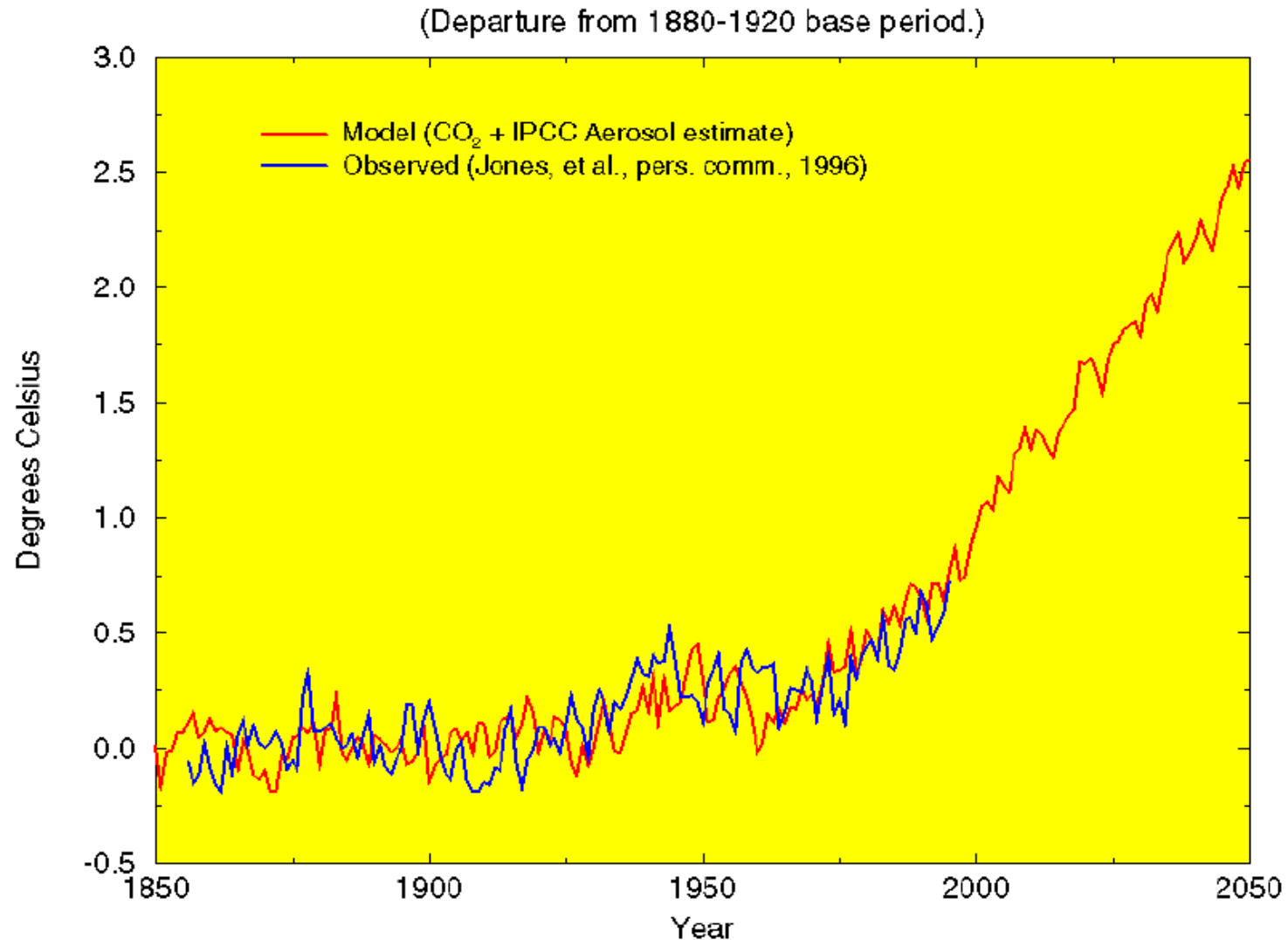


Global monthly ($^{\circ}\text{C}$)
1981 - 2010

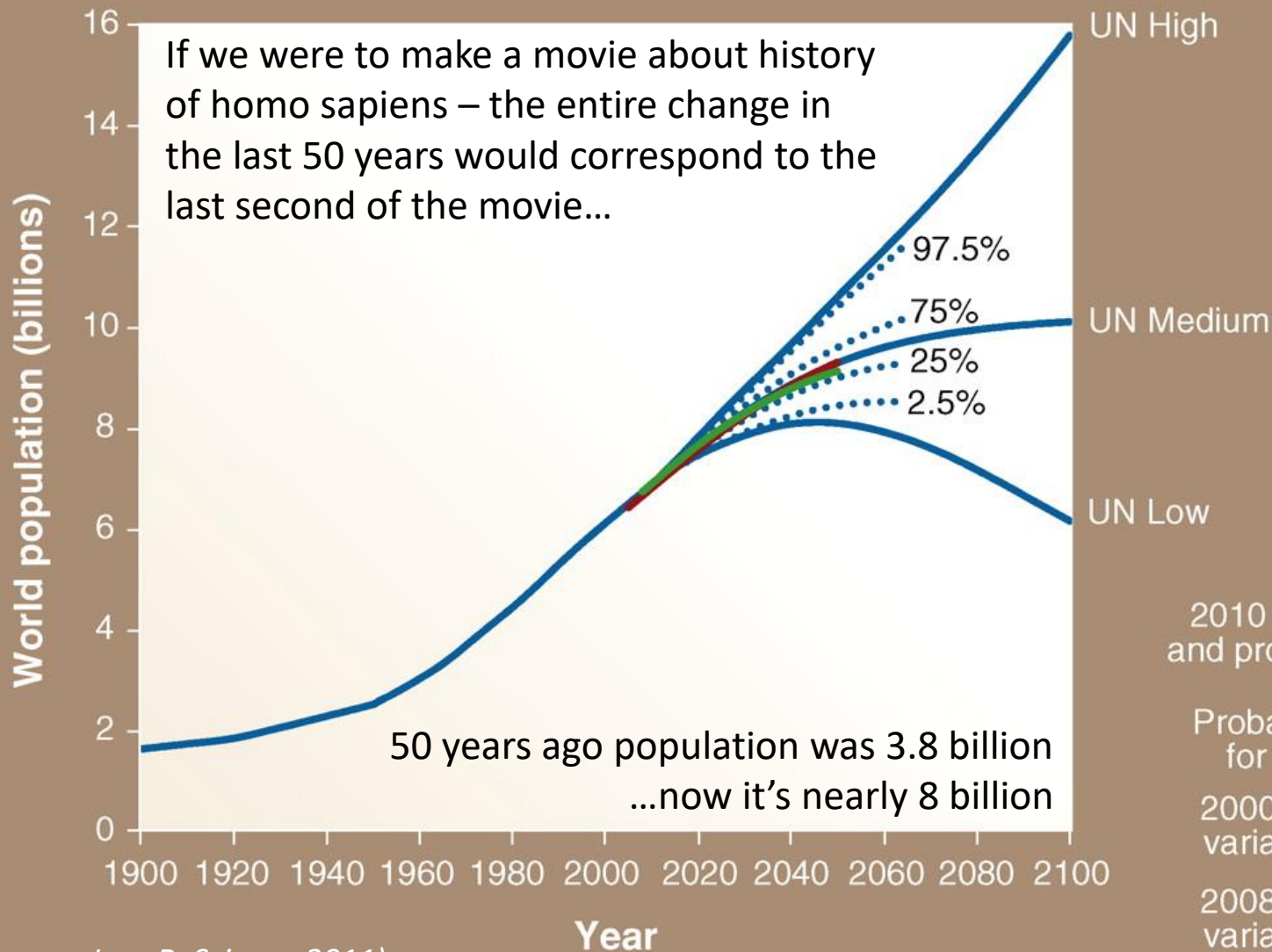


European monthly ($^{\circ}\text{C}$)
1981 - 2010

Global surface air temperature prediction



The Outlook for Population Growth



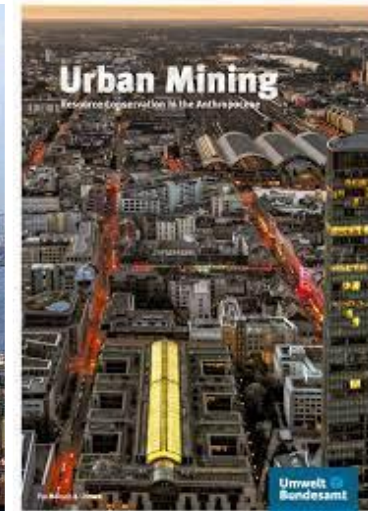
2010 UN estimates and projected variants

Probability bounds for projections

2000 UN medium variant projection

2008 UN medium variant projection³⁰

Tremendous increase in urbanization



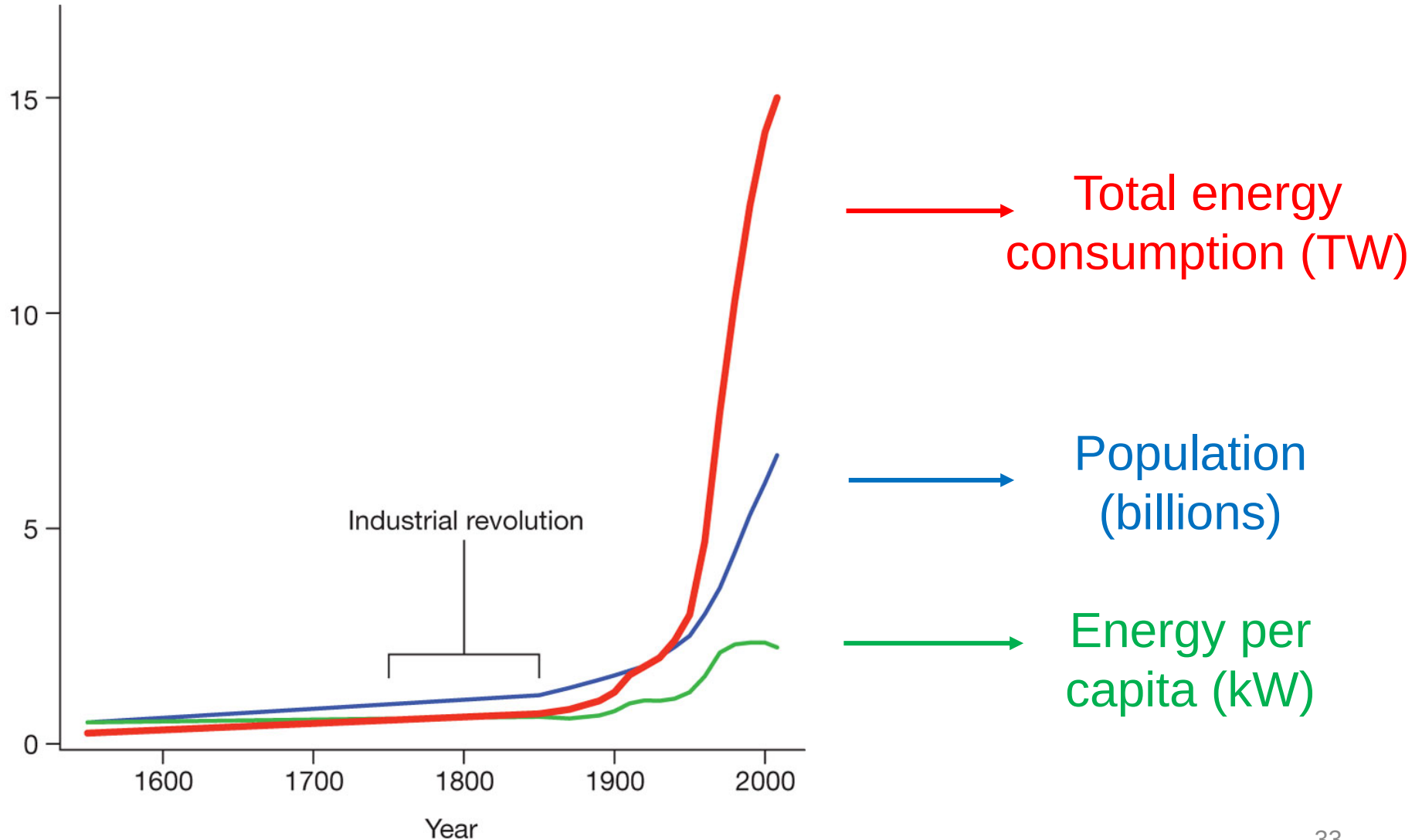
Urban Mining and Recycling

Situation September 2018:

• World population	7'648'962'500
• Birth rate per second	4.4
• People born in 2018, approx.	126'489'600
• People died in 2018, approx.	53'000'000
• Population growth per second	2.3
• Building materials needed	1'127 *

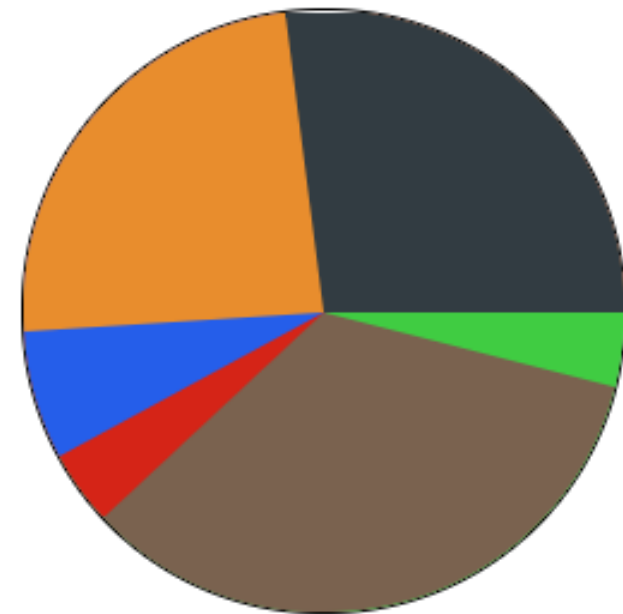
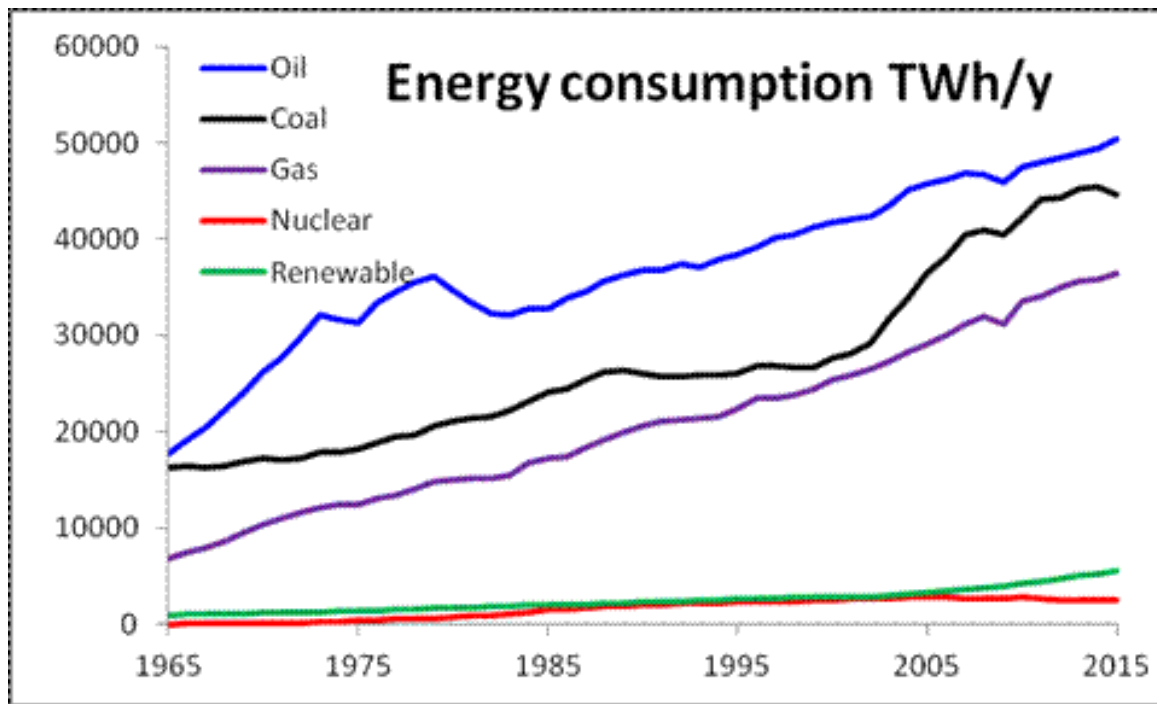
* tons per second !!!

World population and Energy use

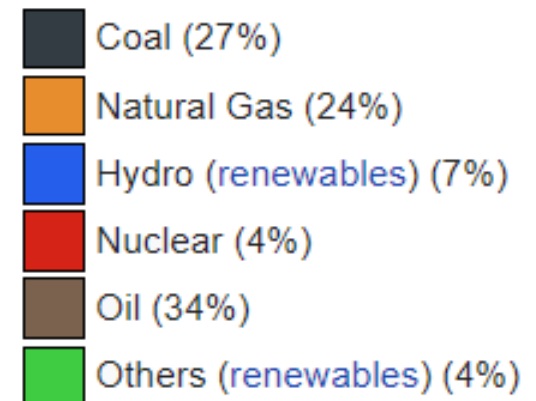


(Source: Ehrlich et al. 2012, Nature)

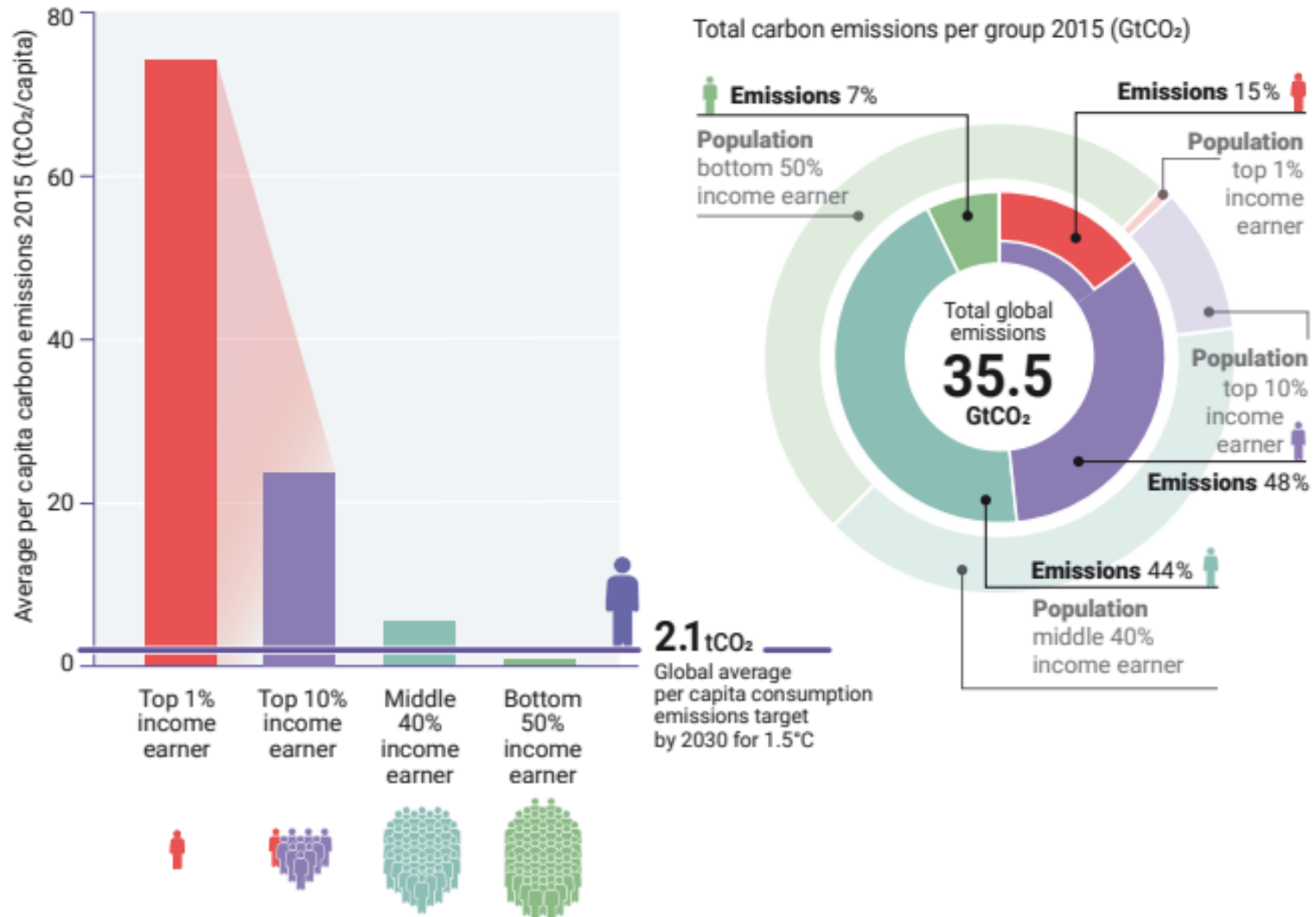
Sources of energy consumption in the world



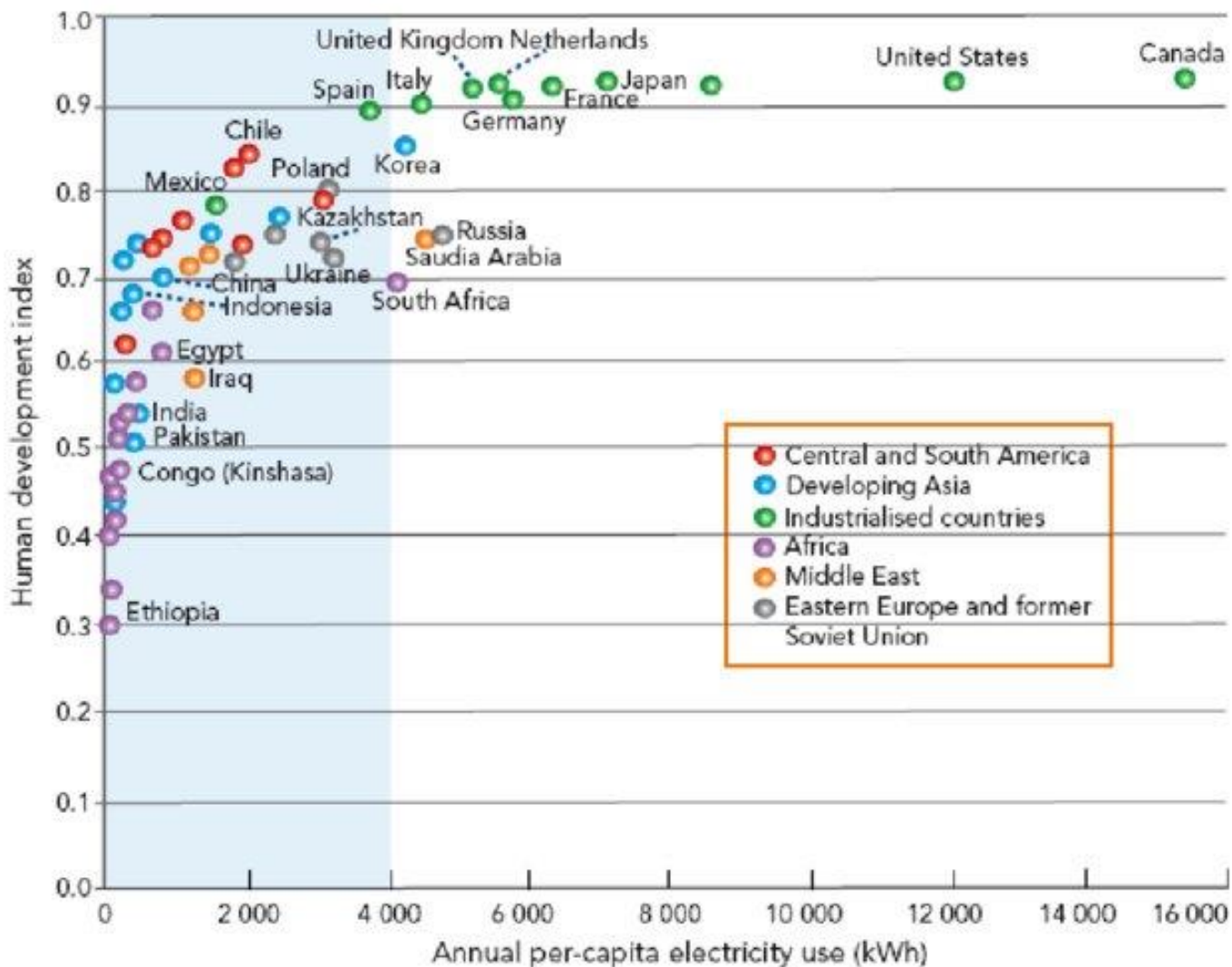
The world's energy consumption (2015)
Each 10000 TWh/y corresponds to an
average value of about 1.142 TW



CO₂ emissions by 4 global income groups



Per-capita electricity consumption and Human Development Index

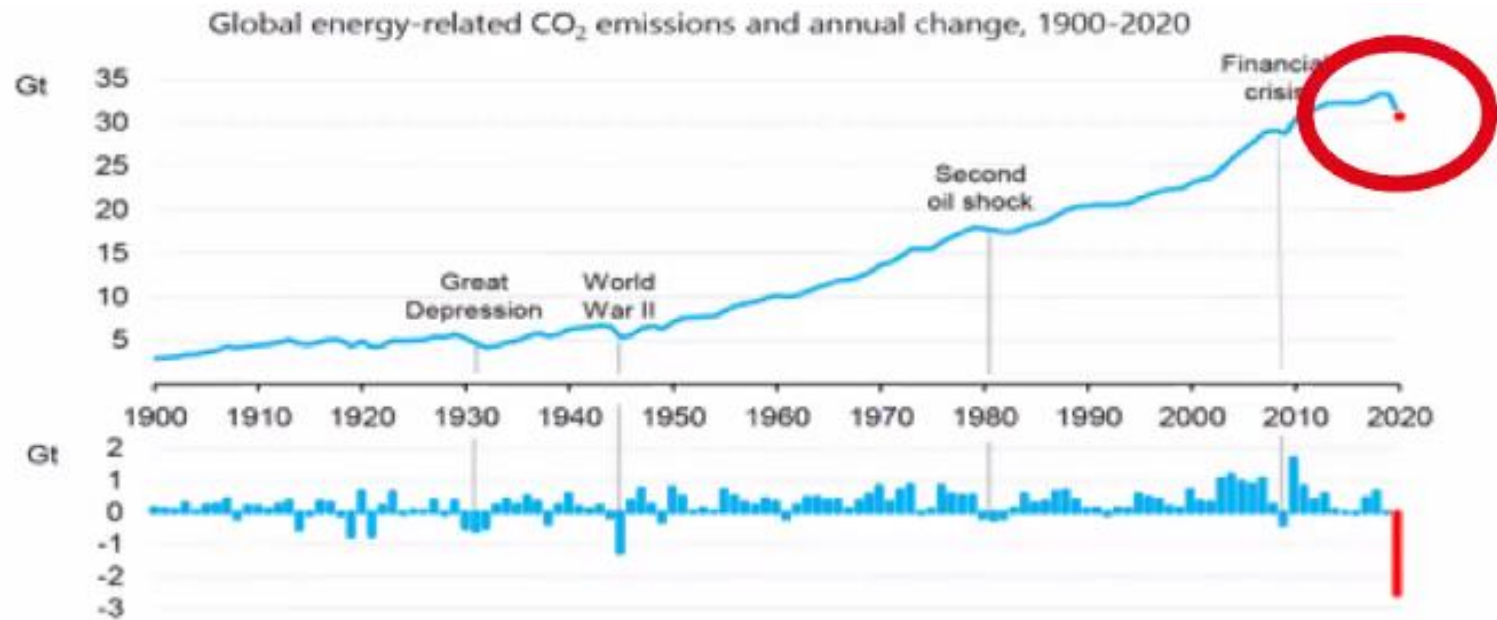


A day of great change is dawning

- 8 billion humans emit to the atmosphere ~8 billion tonnes of fossil carbon per year
- Population average emission rate is thus **1 tonne of C per person per year** or about **3 kgC per person per day**
- Rates vary **a lot** across populations!
 - US average emissions are 15 kgC per person / day (the highest)
 - 5x higher than the global average!
- Question: To let the CO₂ level rise to 450 ppm (inevitable) and global population growth to 9 billion, what average per-capita emission of C must be?
 - Answer: It must be reduced from 3 kgC to 1 kgC per person per day

Trend of CO₂ emissions

- CO₂ emission dropped the most ever due to the COVID-19 crisis



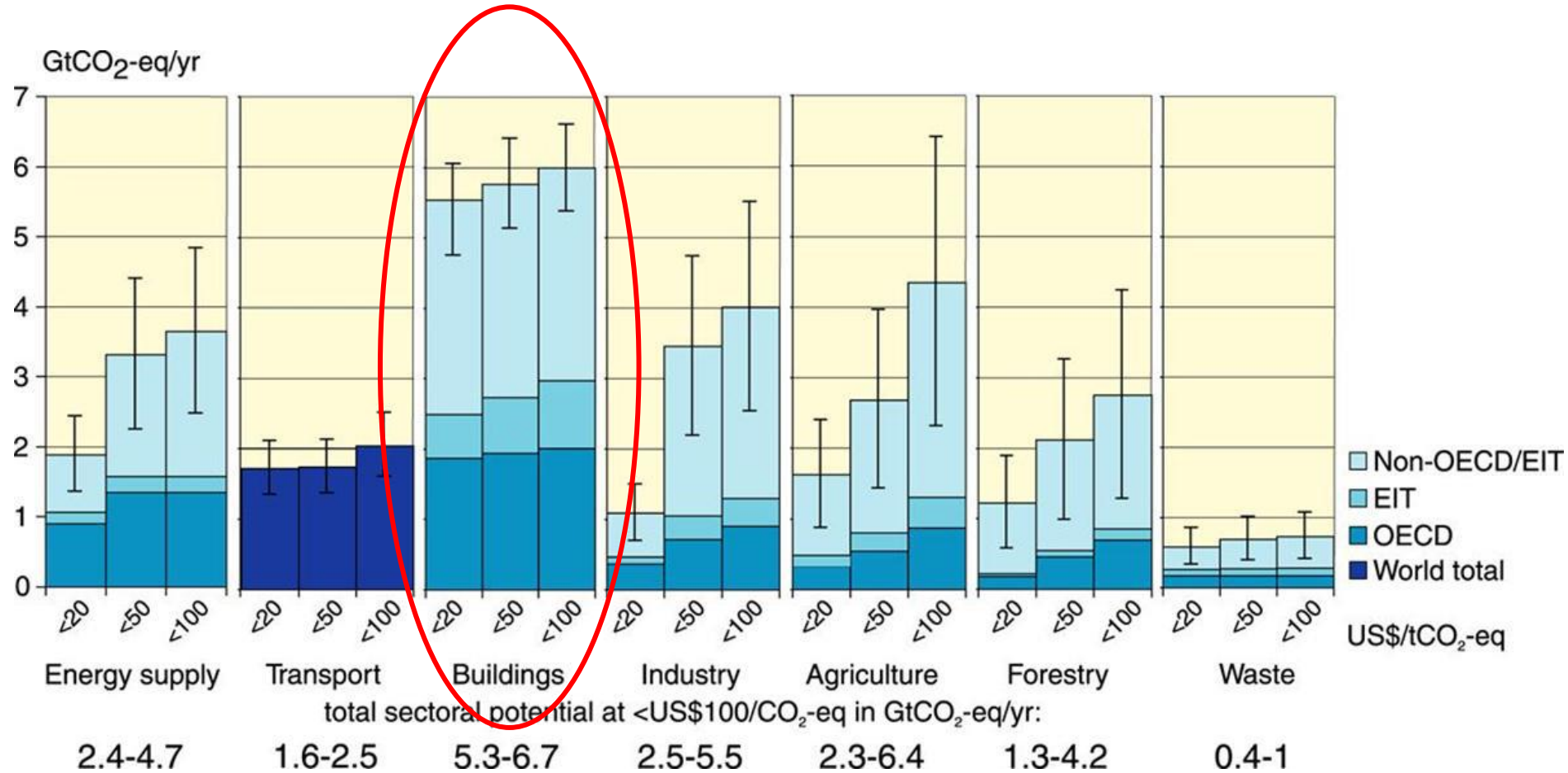
- Global energy-related CO₂ emissions fell nearly 8% in 2020 (lowest in a decade) mostly due to reduced coal use
- However, there was a large rebound soon after and is expected to continue during post pandemic

A day of great change is dawning

How to get from 3 kgC to 1 kgC per person per day?

Where should we focus our efforts?

Where should we focus our efforts?



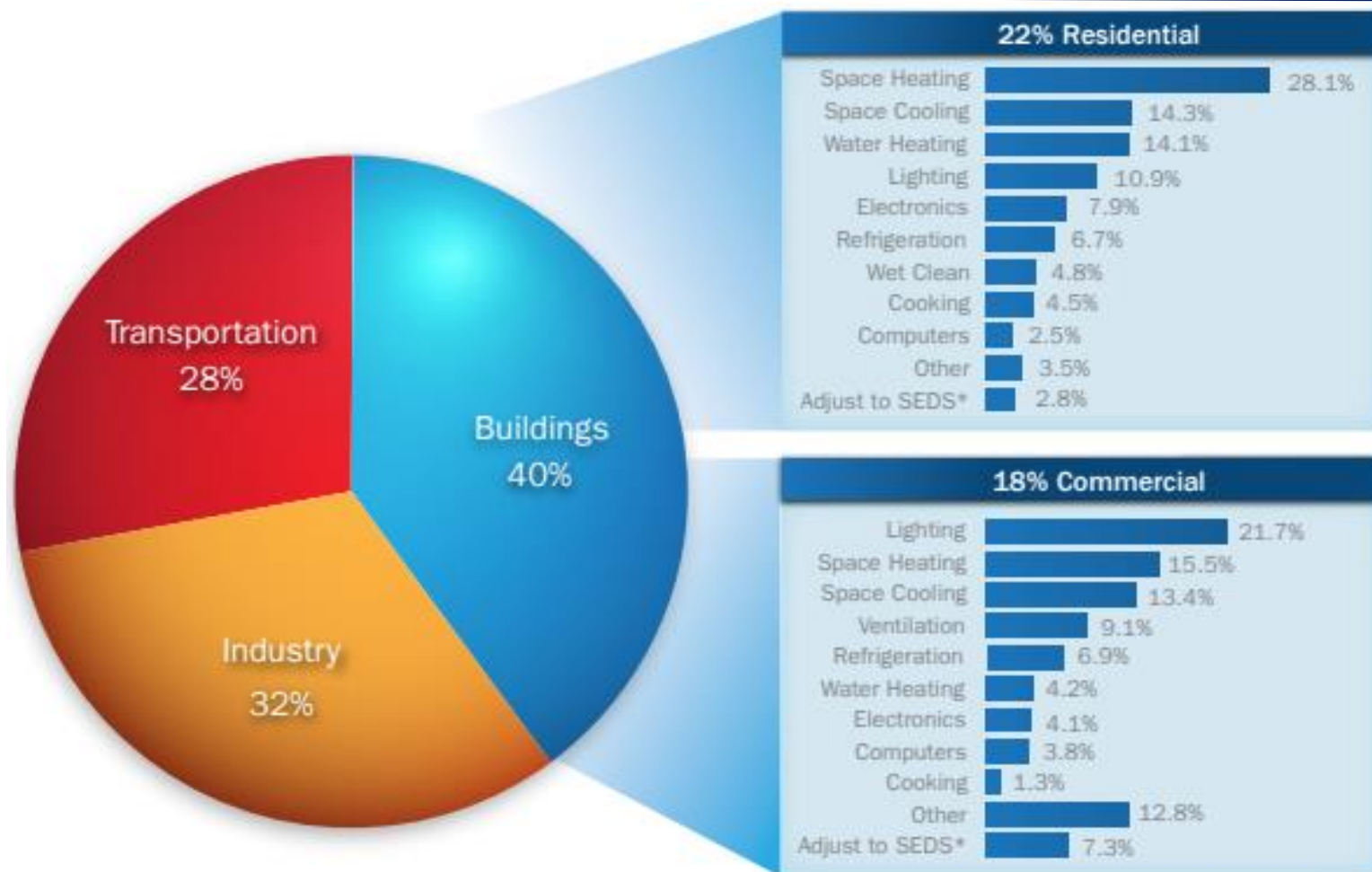
Any questions? See you in 15 mins...



Lets sum up a few key points so far:

- The climate is changing & the cause is human activity
- Impacts are obvious – air, soil and oceans started to send us invoices
- Energy use in buildings has the strongest (but not sole) influence
- The extent of future impacts depends on what we do now

US energy use in residential and commercial buildings, 2008



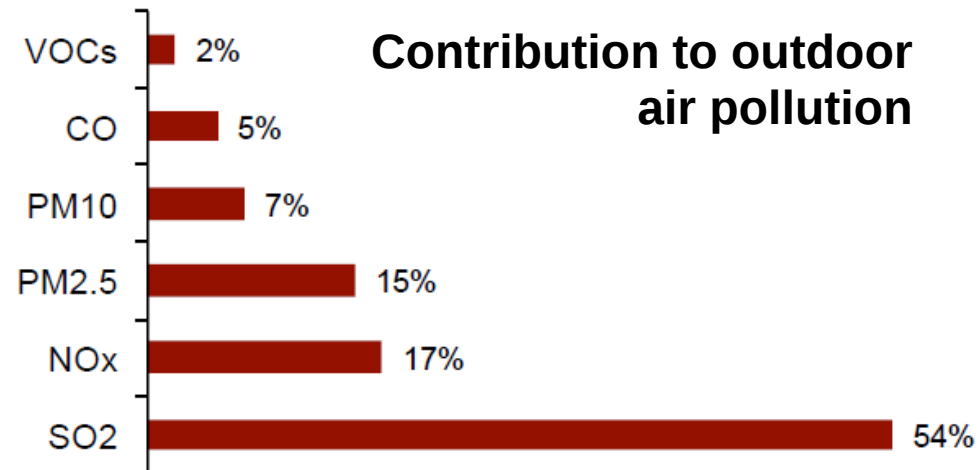
Building consume 40% of primary energy. Of that, 22% is consumed in residential buildings and 18% in commercial buildings

Environmental impact of buildings

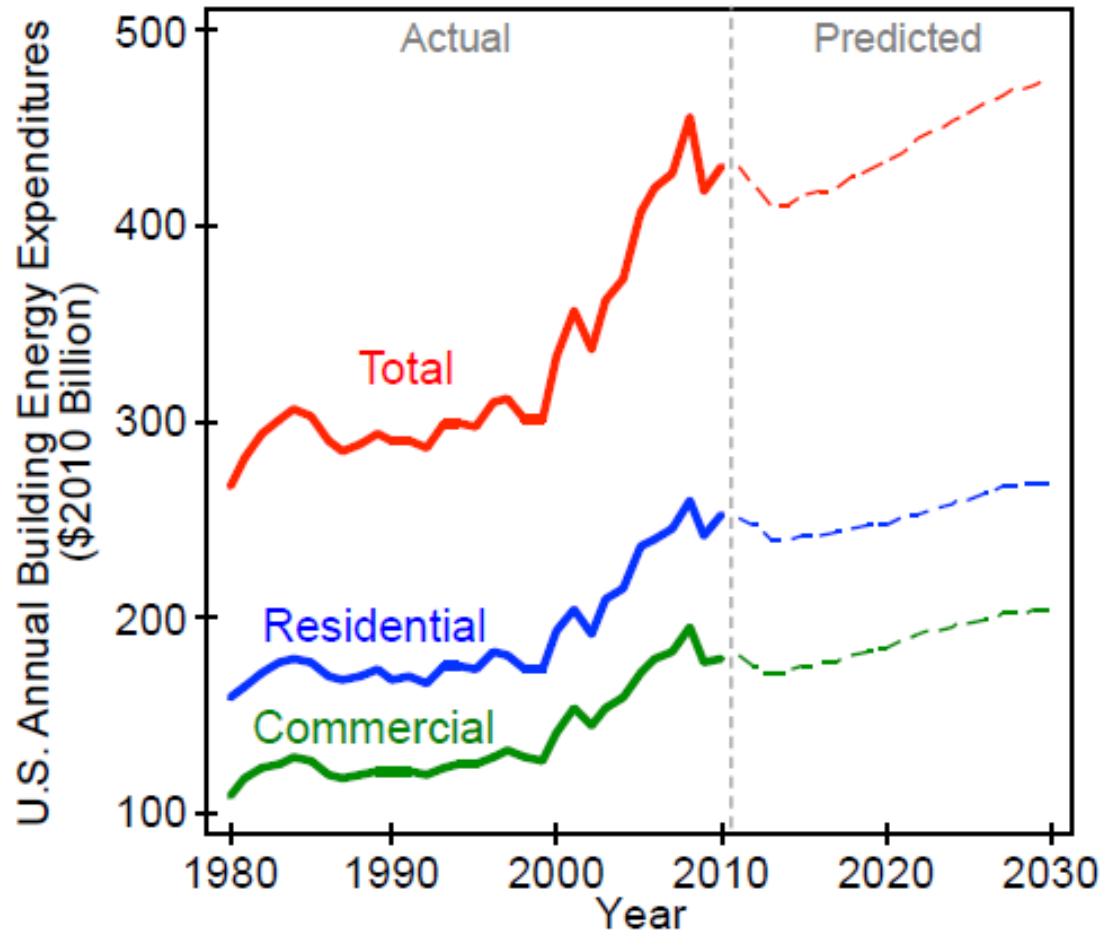
- 72% of total U.S. electricity consumption
- 38.9% of total U.S. primary energy use
- 39% of total U.S. CO₂ emissions
- 40% of landfill material in the U.S.
- 13% of potable water in the U.S.



Buildings in the U.S. account for ~7% of the total amount of energy used in the world



Building energy use costs *a lot* of \$\$\$



U.S. building energy expenditures totaled
~\$430 billion in 2010

Objectives and climate strategy in Switzerland



- The climate policy of Switzerland aims at reducing the emissions of CO₂ by 20% by **2020** (interim target) by 50% by **2030** and by 70-85% on the horizon **2050** compared to emissions in 1990
 - Buildings: Reduction of GHG of 82% by **2040**
 - Read about **Energy Strategy 2050** here:
https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050.html#tab_content_bfe_en_home_politik_energiestrategie-2050_jcr_content_par_tabs
- Ambitious targets, but hey, **we already know that it won't be enough!**
- We need new building standards based on a life cycle approach.

Stock of buildings in Switzerland: Energy consumption and CO₂ emissions



Source: Bernard Nicod



Source: Echaffaudage-Vevey.ch



Source: Chantiers & Rénovation

- **1.7 million** residential buildings in Switzerland in 2016
- Construction and operation of buildings: about **50% of the final energy consumption and the CO₂ emissions**

After-class thinking...



-

What do we do to reduce the consumption of energy to meet targets of Energy Strategy 2050?

-

How to substitute the prevailing fossil fuels with renewable energies in buildings? Is reliance on renewables enough to overcome the challenge?

-

Which are the economic and environmental implications?

Embodied carbon: Construction practices

Bird's Nest
Beijing



1300 kg CO₂e/m²

Olympic Stadium
London



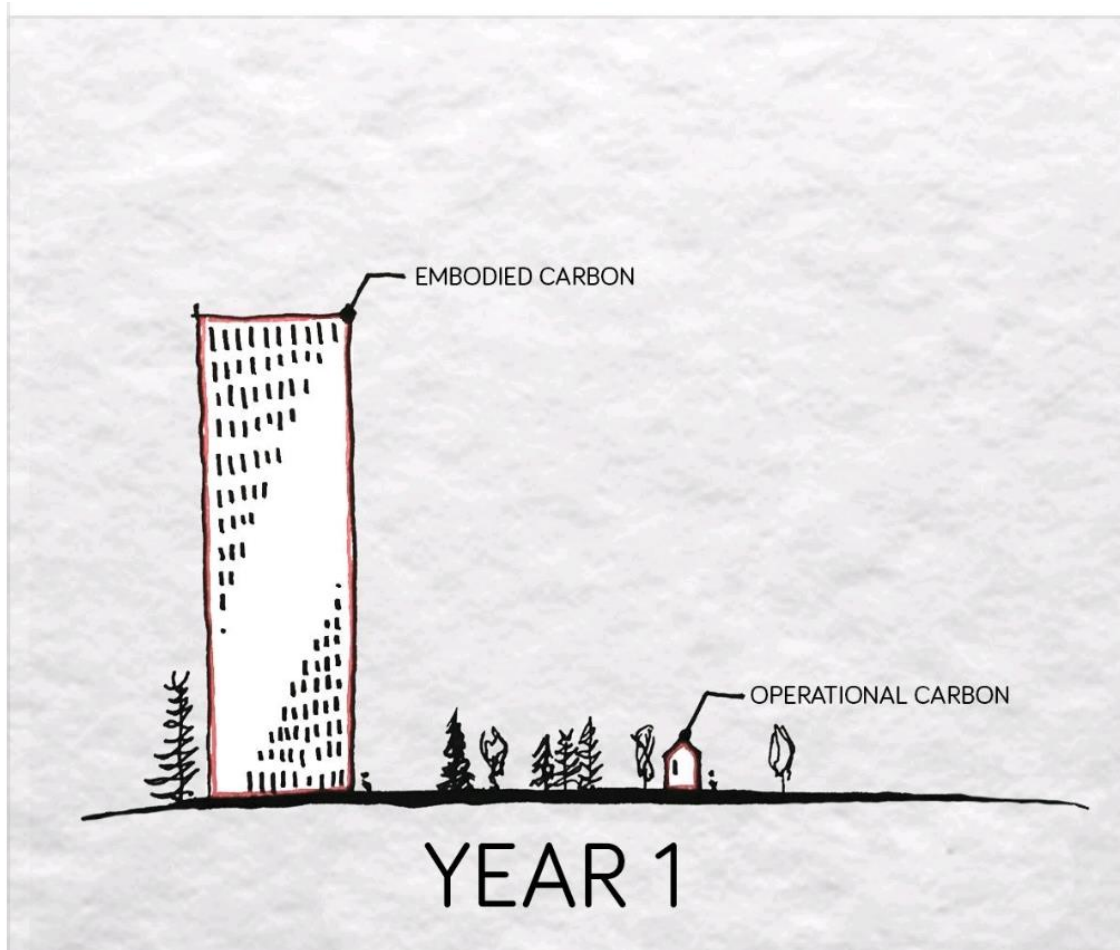
250 kg CO₂e/m²

Mapungubwe Centre
South Africa



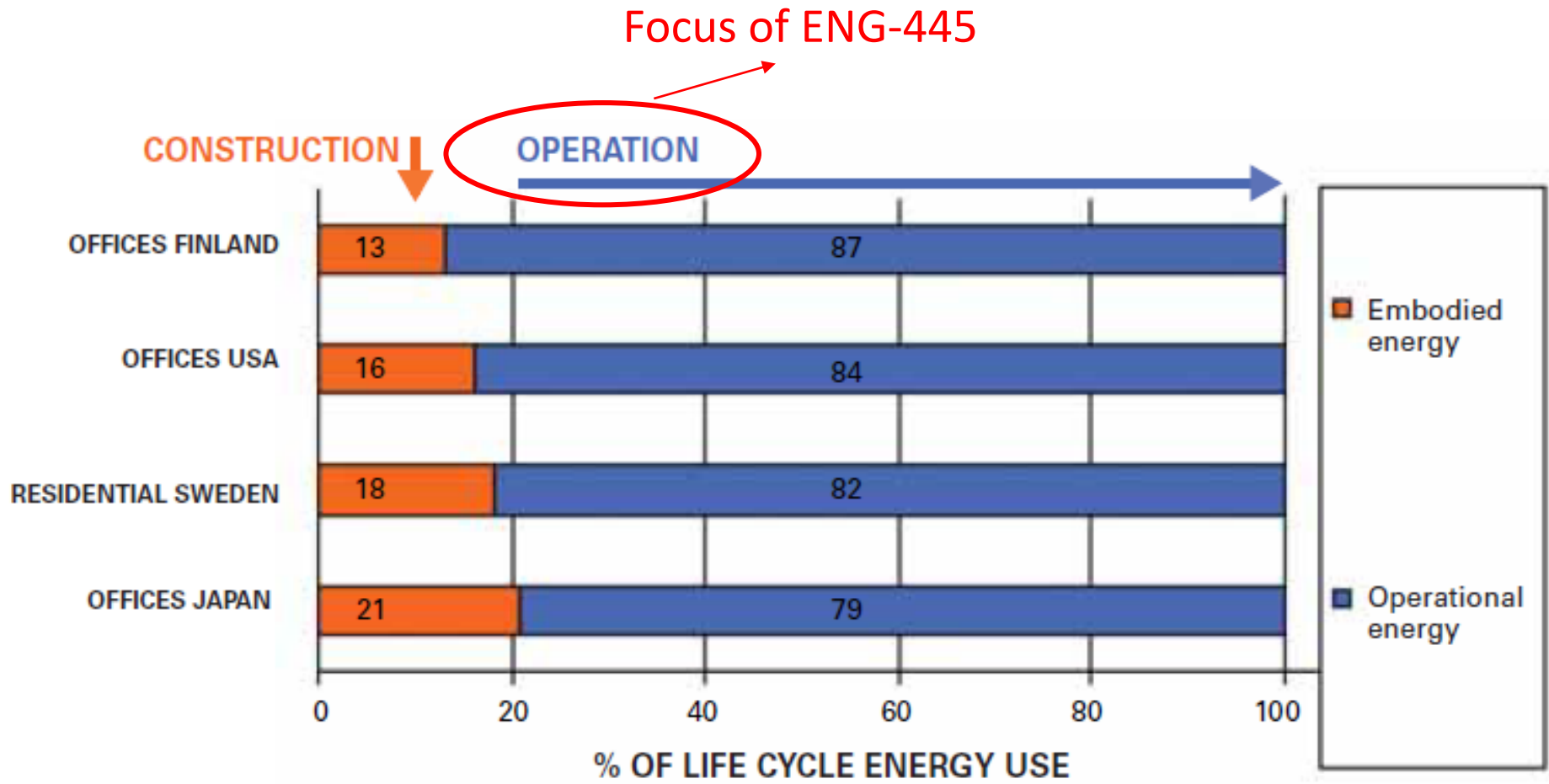
60 kg CO₂e/m²

Embodied vs. Operational emissions...

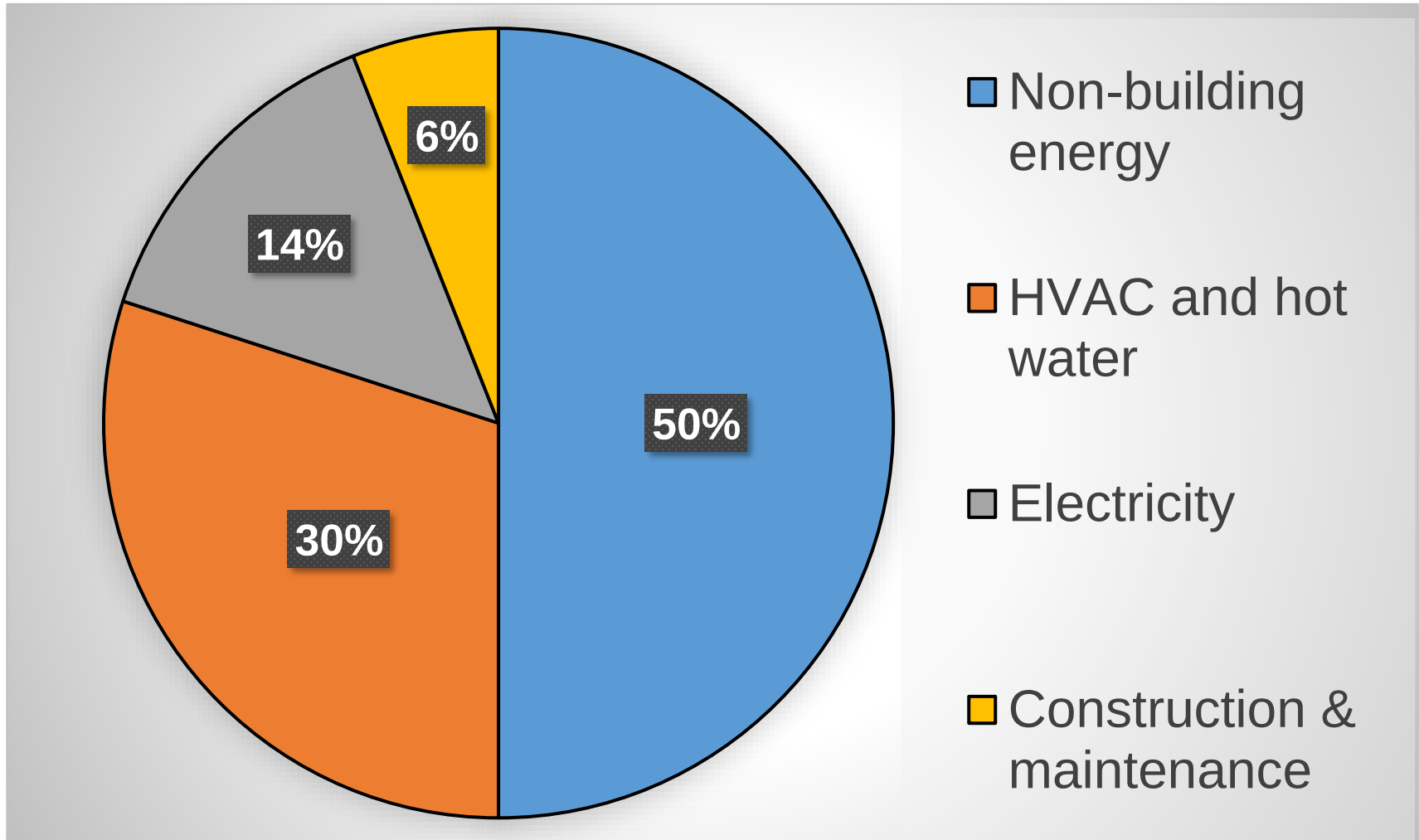


In order to address climate emergency, we must focus both on **operational carbon**, which is the carbon load created by the use of energy to condition and power a building (focus of ENG 445), as well as **embodied carbon**, which is the carbon that is released in the manufacturing, production, and transportation of our building materials. In early building life, embodied energy could be large, although it's lower compared to operational energy overall

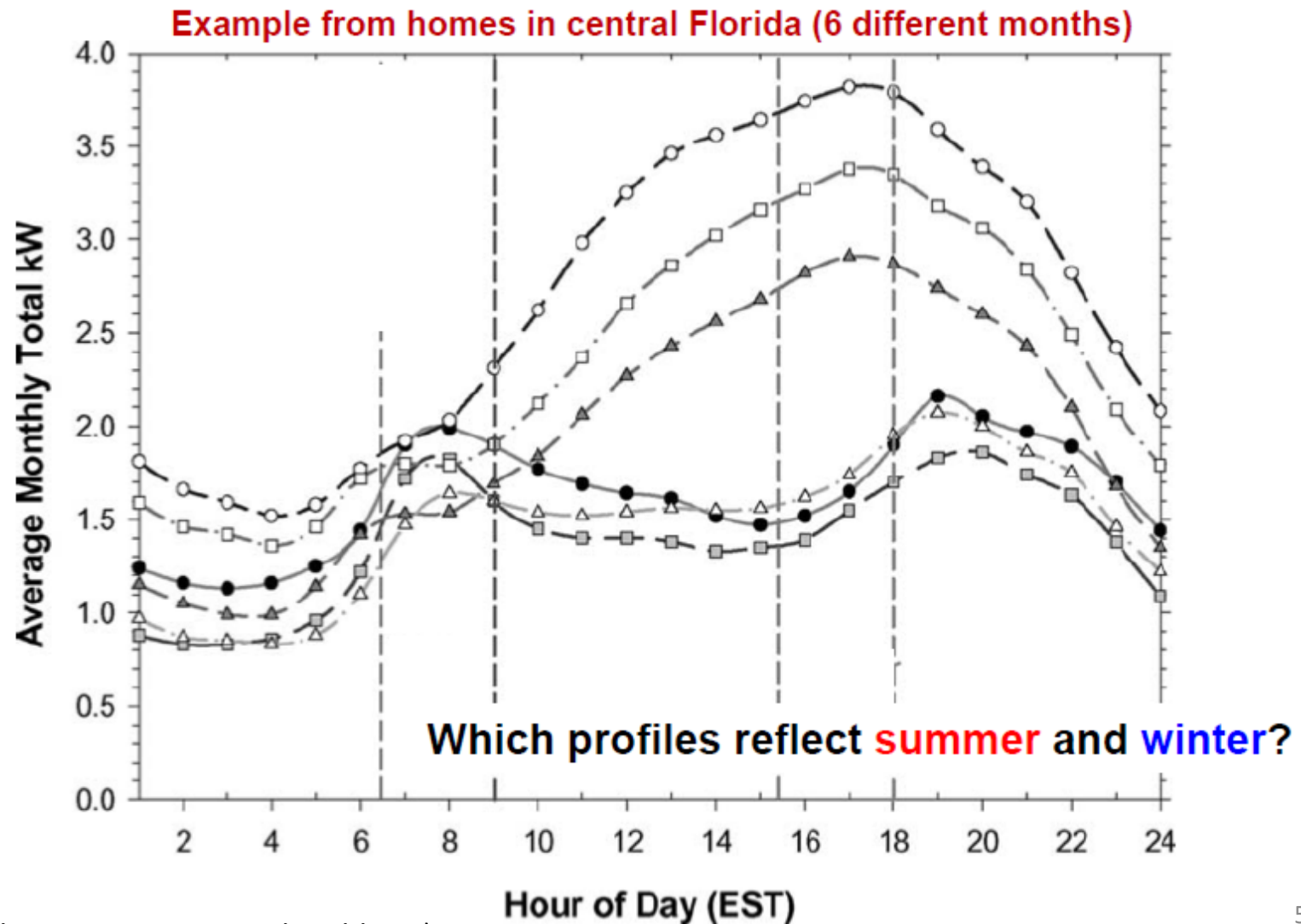
Example of life cycle energy use of buildings



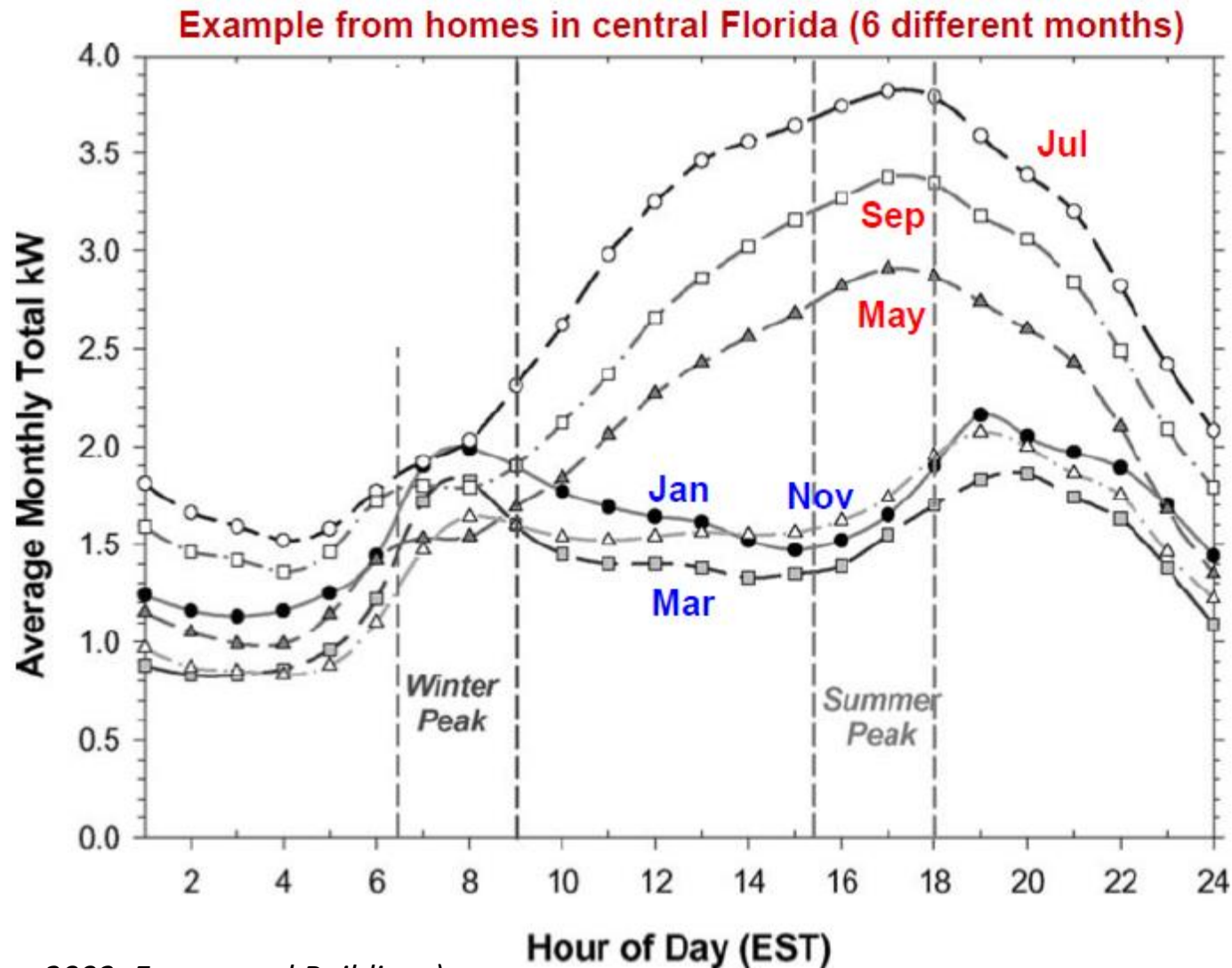
Building energy use in CH: 50% !!!



Understanding energy use in buildings



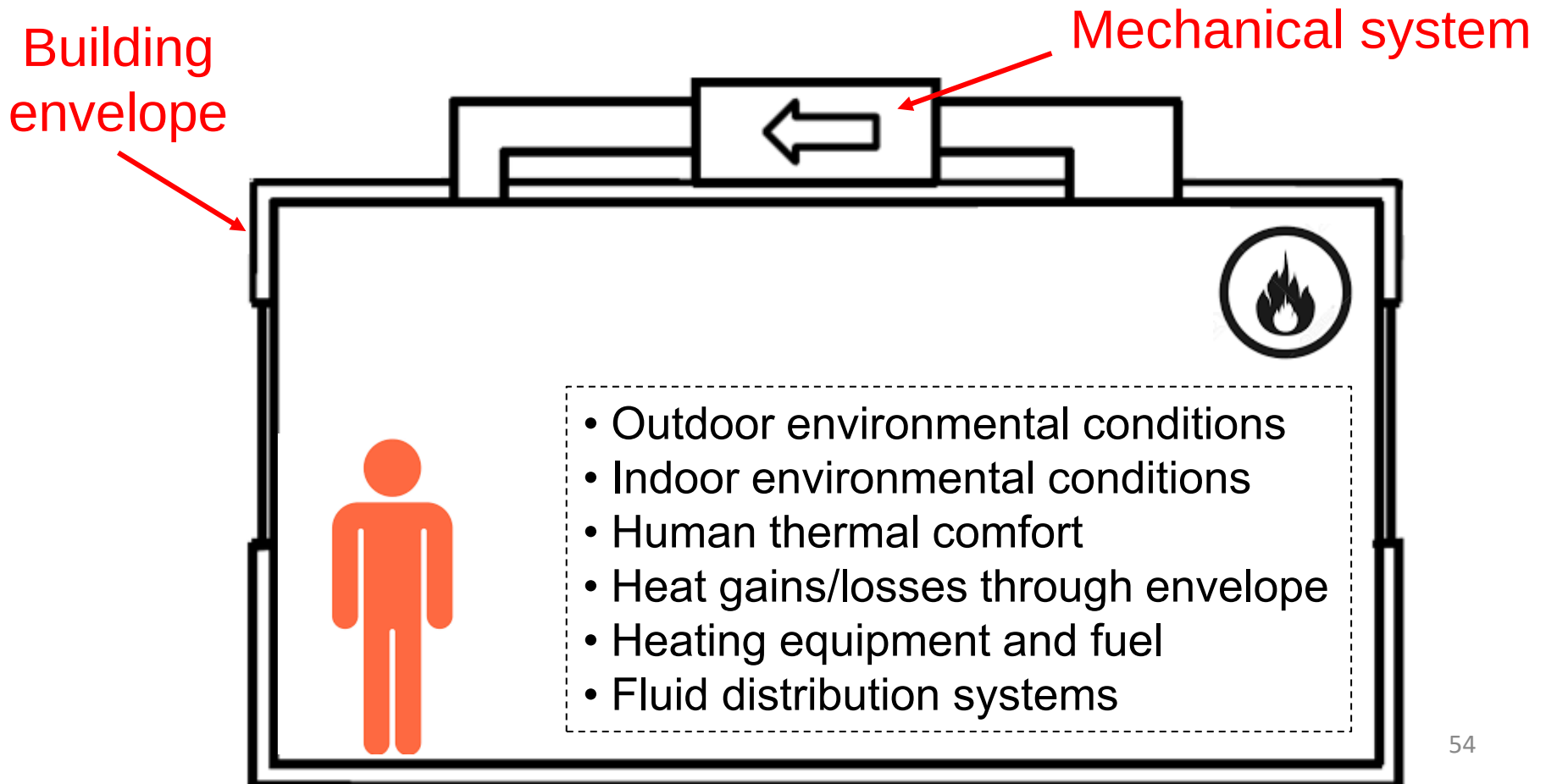
Understanding energy use in buildings



(Source: Parker 2003, *Energy and Buildings*)

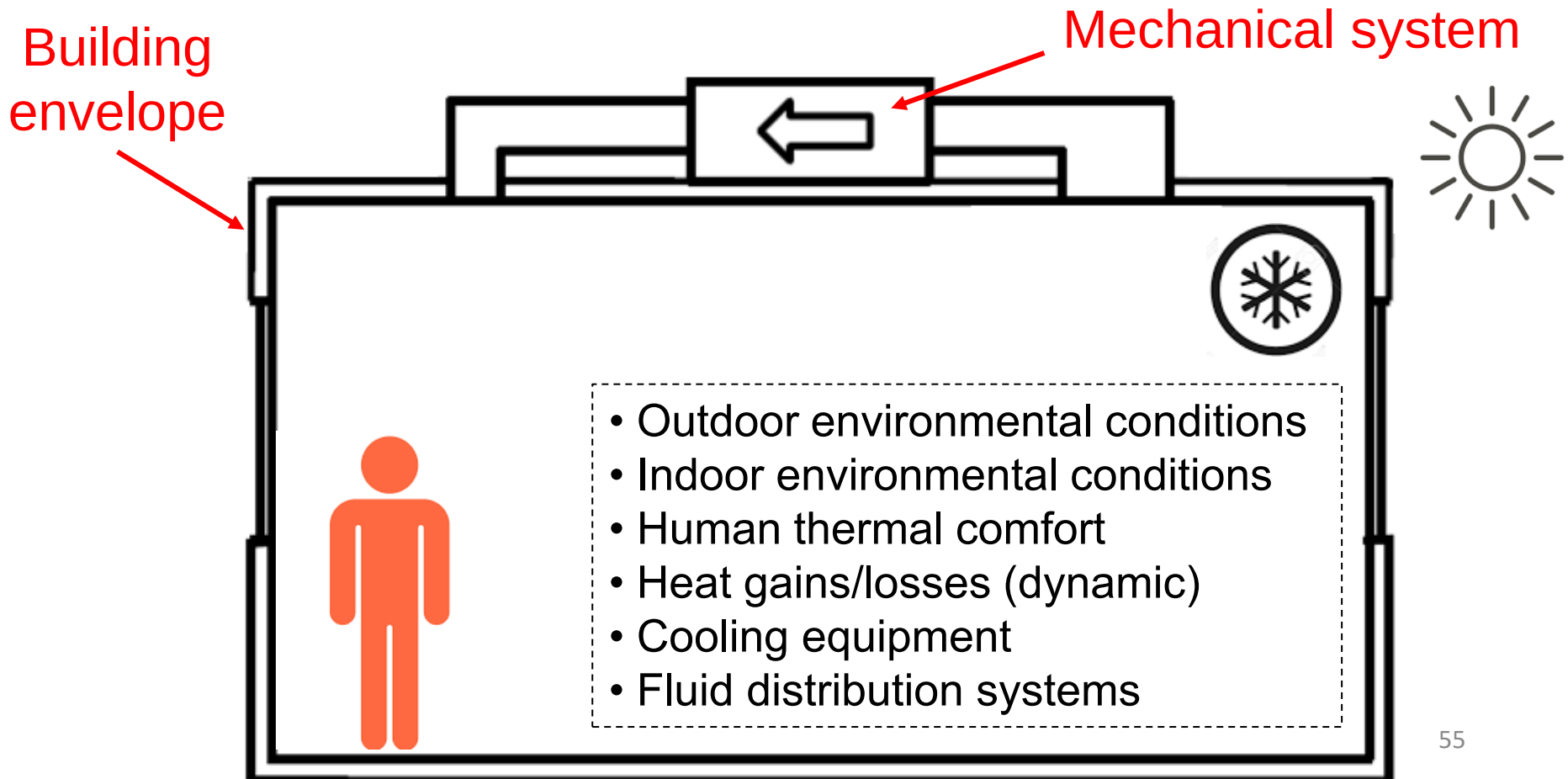
Building energy use for Heating

What are the key factors influencing energy use for **heating**?

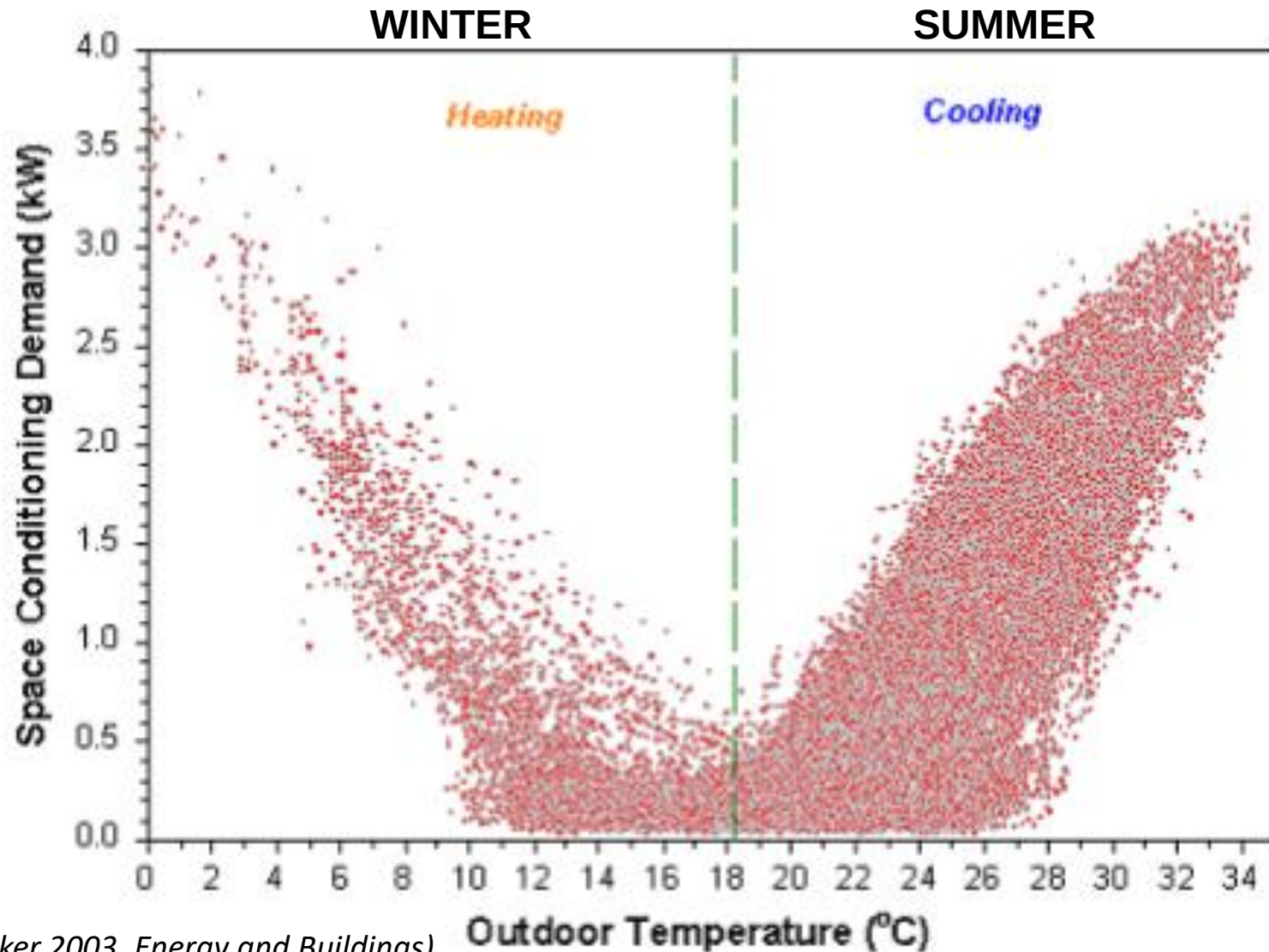


Building energy use for **Cooling**

What are the key factors influencing energy use for **cooling**?



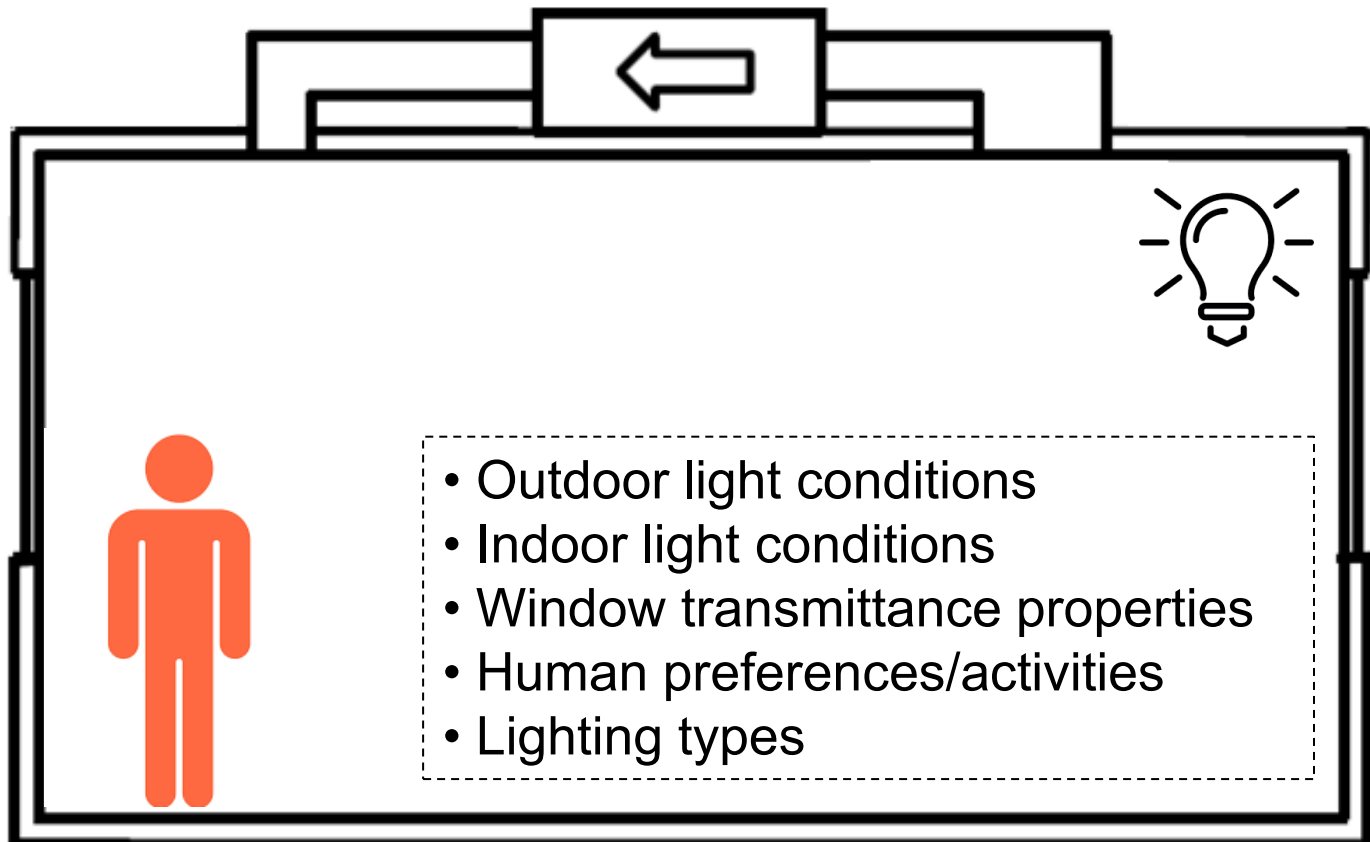
Understanding energy use in buildings



(Source: Parker 2003, Energy and Buildings)

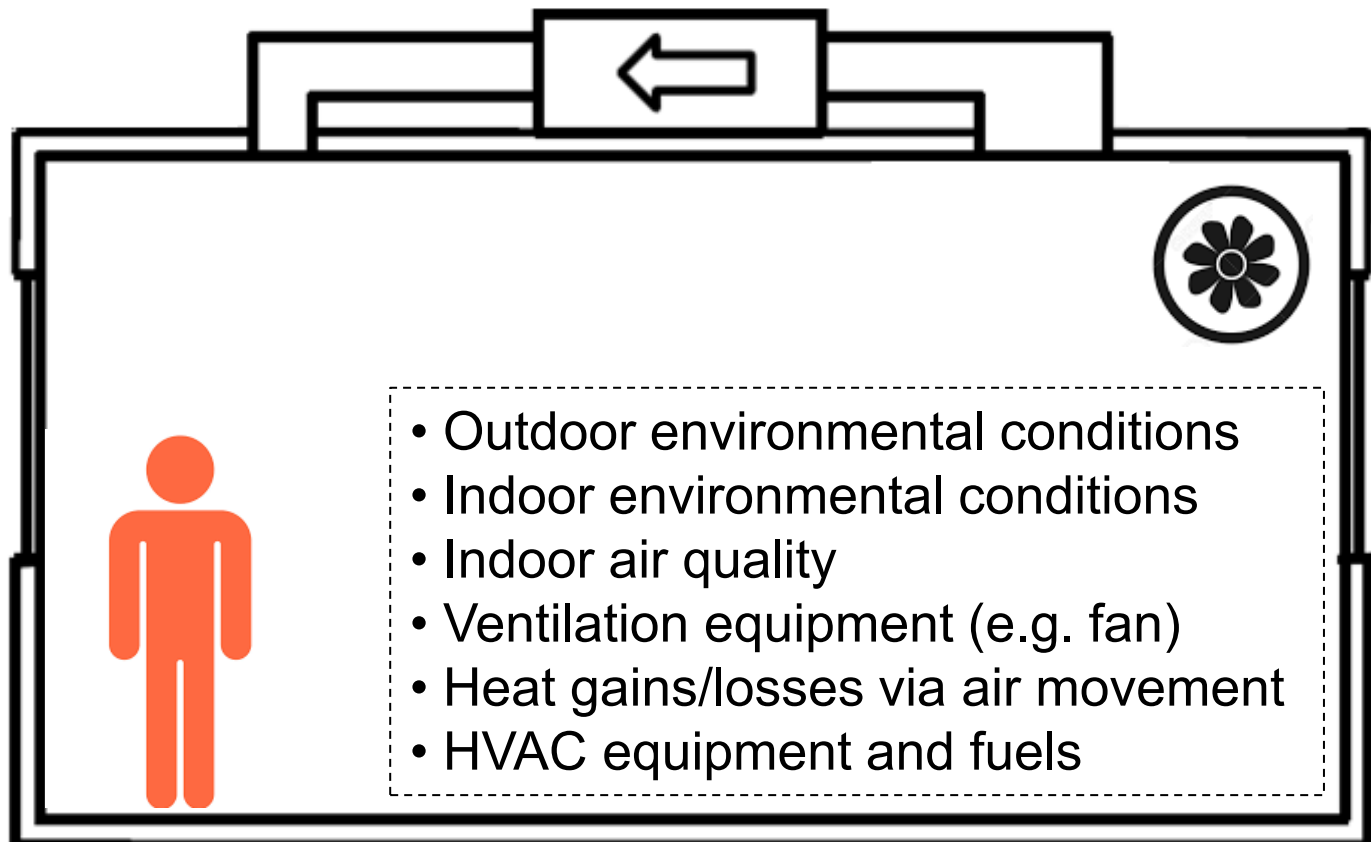
Building energy use for **Lighting**

What are the key factors influencing energy use for **lighting**?

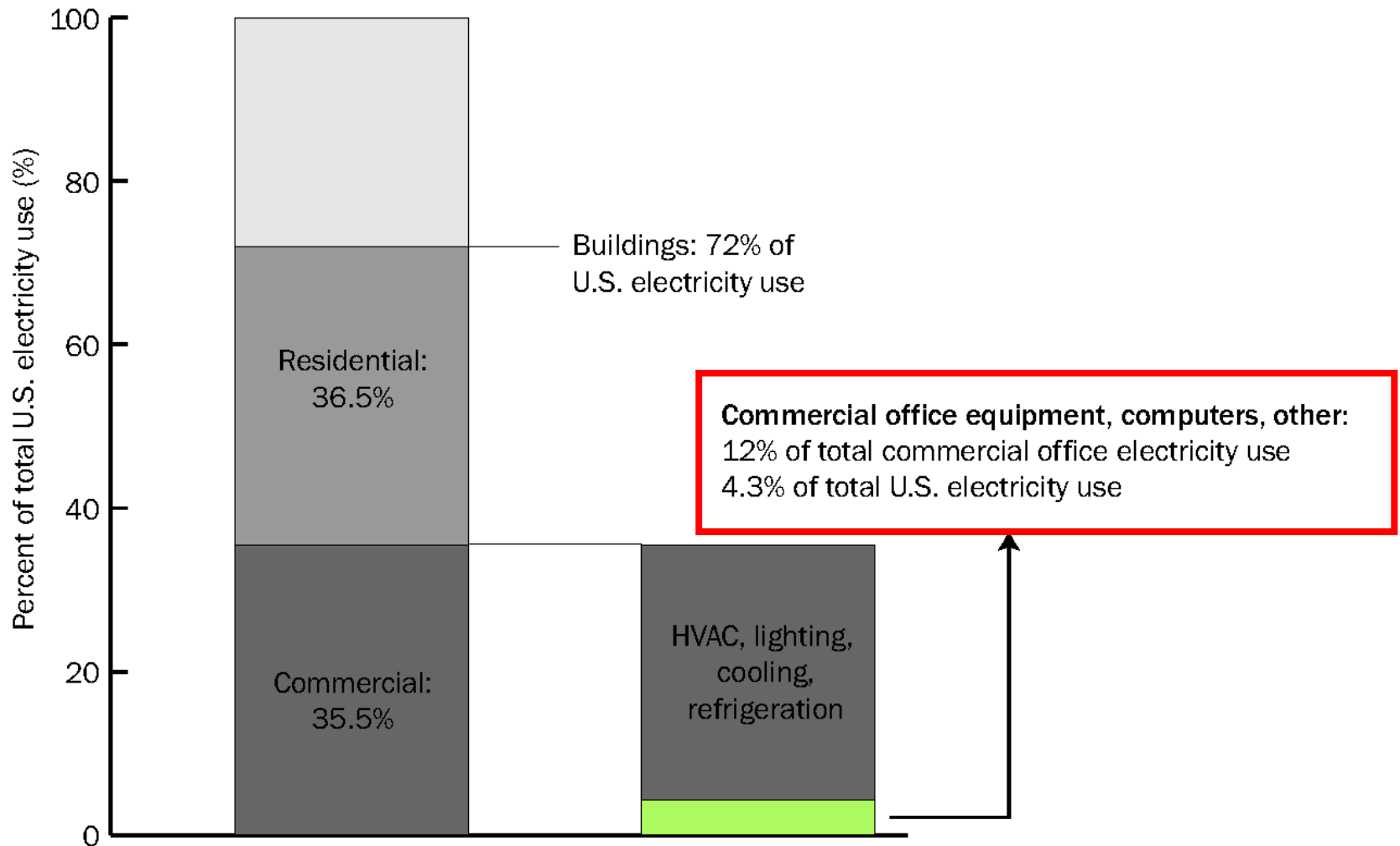


Building energy use for **Ventilation**

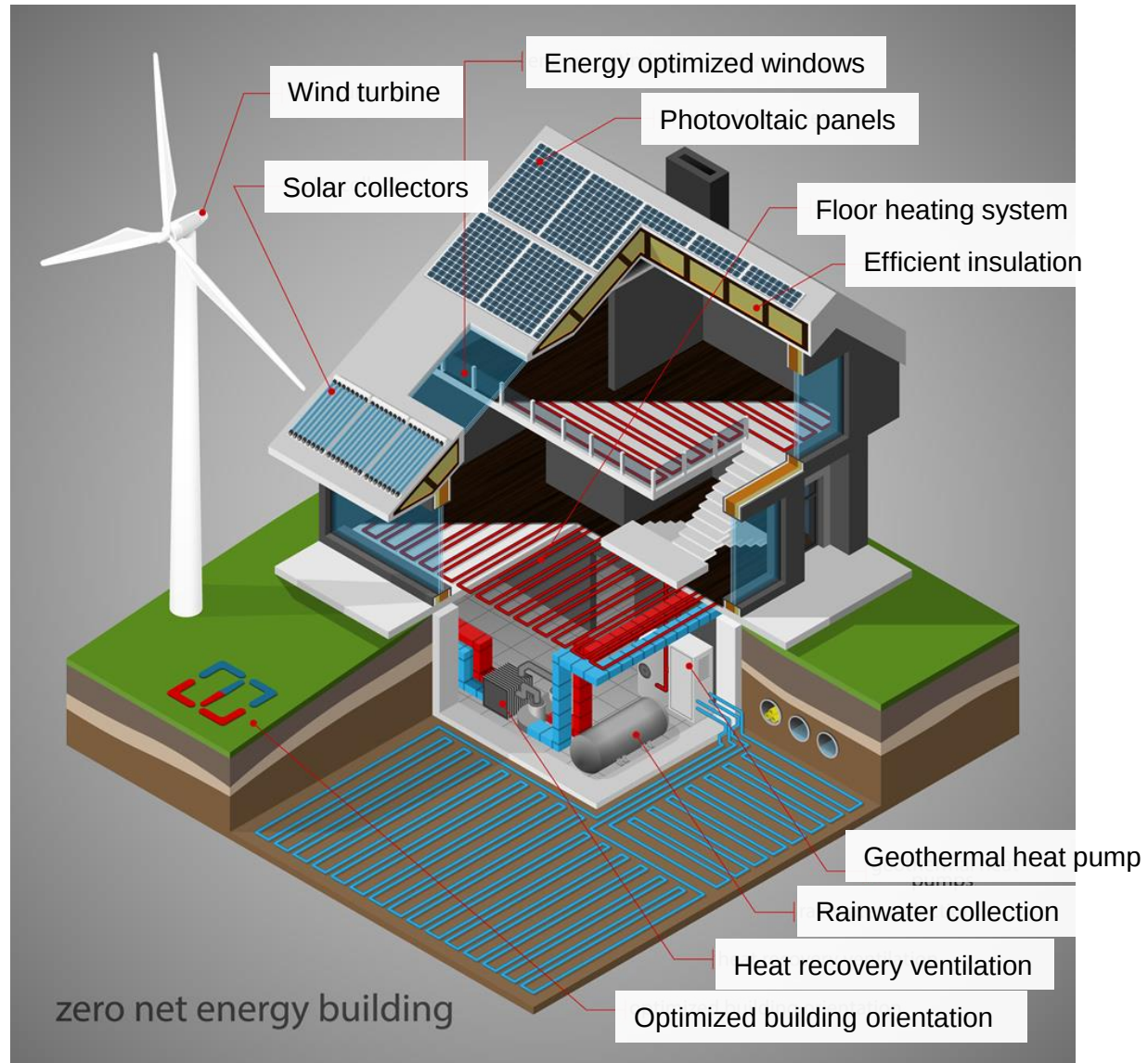
What are the key factors influencing energy use for **ventilation**?



Building energy use: Plug loads



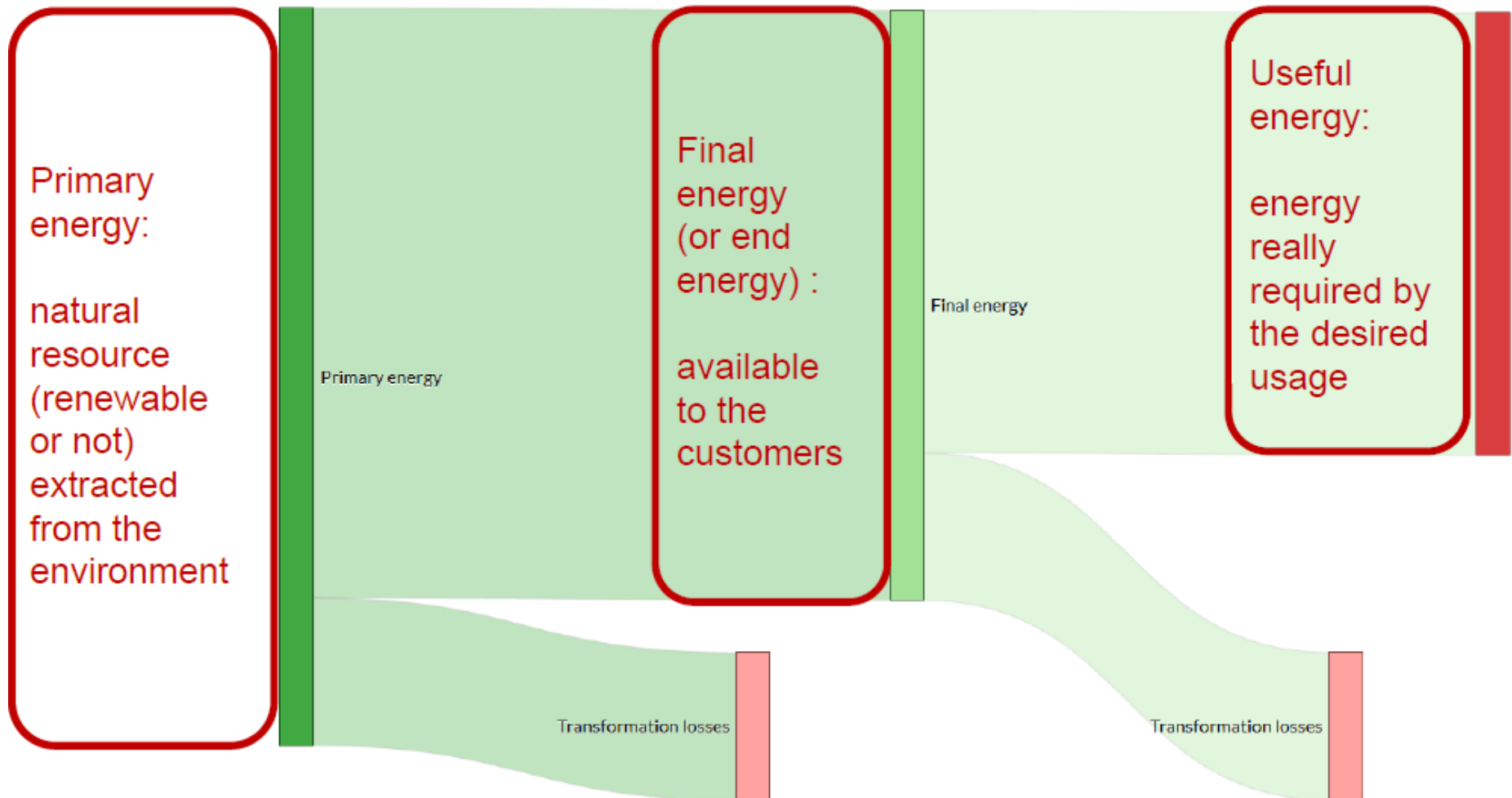
What is a Net Zero Energy Building?



Net Zero Energy Buildings: Definition

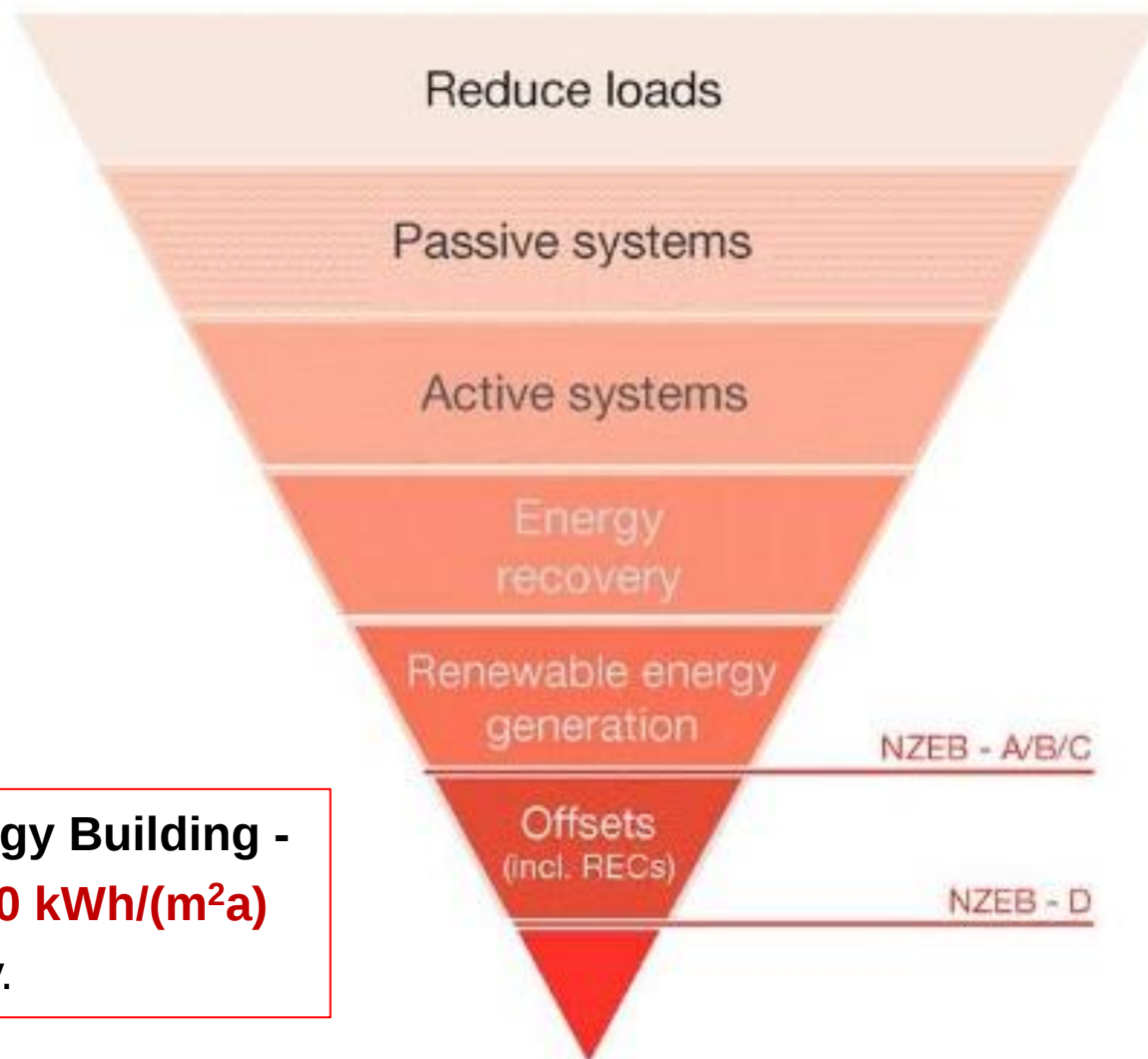
- **Net Zero Energy Building (ZEB)** - Energy use of **0 kWh/(m²a)** primary energy. Net ZEB is typically a grid connected building with very high energy performance
- **Nearly Net Zero Energy Building (ZEB)** - Technically reasonable achievable national energy use of **> 0 kWh/(m²a)** primary energy achieved with best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal
- **Primary (or Source) Energy** - Energy from *renewable* and *non-renewable* sources which *has not undergone* any conversion or transformation process
- **Delivered (or Site) Energy** - Energy, expressed per energy carrier, supplied to the technical building systems through *the system boundary*, to satisfy the uses taken into account (e.g. heating, cooling, ventilation, domestic hot water, lighting, appliances etc.) or to produce electricity.

Primary / Delivered / Useful energy



- Coal or wind or waterfall or solar radiation or ... (primary energy)
- Electricity (delivered energy)
- Light or heat or information & communication services or ... (useful energy)

Net Zero Energy Buildings: Setting priorities



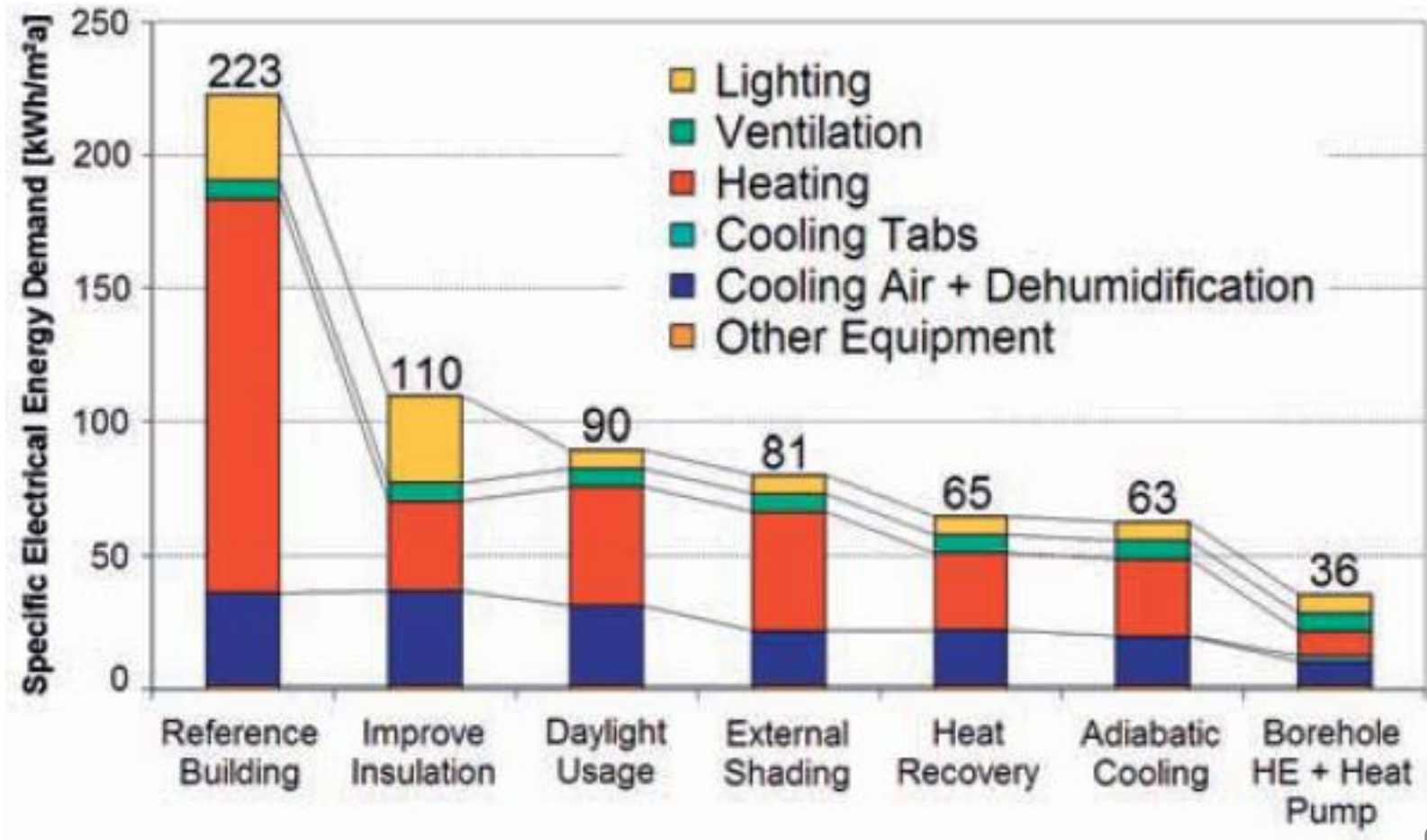
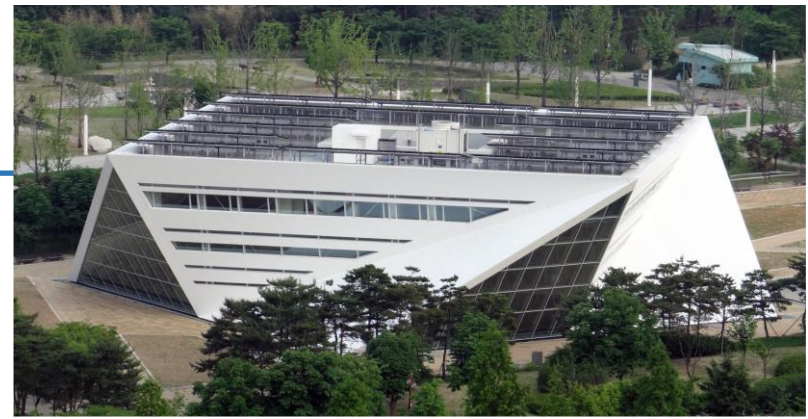
Net Zero Energy Building -
Energy use of **0 kWh/(m²a)**
primary energy.

What if we focus on renewable energy only?



Net Zero Energy Buildings

Energy Dream Center Seoul (2012)



Consider: Sufficiency vs. Efficiency

Is technology sufficient to solve the issue?

Sufficiency	Efficiency
Doing the right things	Doing things right
Tackles causes of climate change and the ecological crises	Tackles symptoms of climate change
Requires system change	Incremental improvement of individual technologies
Absolute reduction of the demand for all natural resources	At the best relative reduction of energy and materials consumption
The cost of climate neutrality is shared	Individuals bear the cost of efficiency improvement
Equity and fairness considerations	Competition and profits considerations

Understanding building energy use

It all starts with understanding **building and material properties** and **heat and mass transfer processes**

- You will play with different parameters throughout the semester



STRETCH !



What is comfort?



Human comfort in buildings

Human Comfort $\neq$ Thermal Comfort



Age, Gender
Health and psychological status
Activity, Clothing
Access to food and drink
Safety, etc.



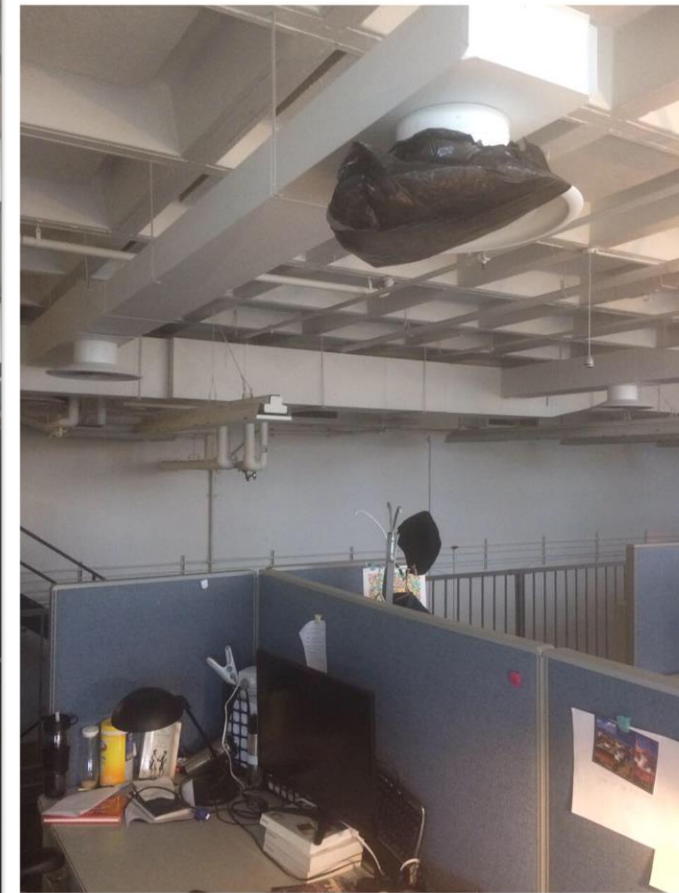
Personal

Comfort and the role of buildings

- Any building has primarily a protective role to occupants
- Occupied buildings should meet human comfort requirements
- Comfort depends on various aspects which should be considered as a whole
- What happens if comfort is not considered as a whole?



Comfort and buildings



Code compliance may not be sufficient

Comfort and buildings

Good design may not be sufficient

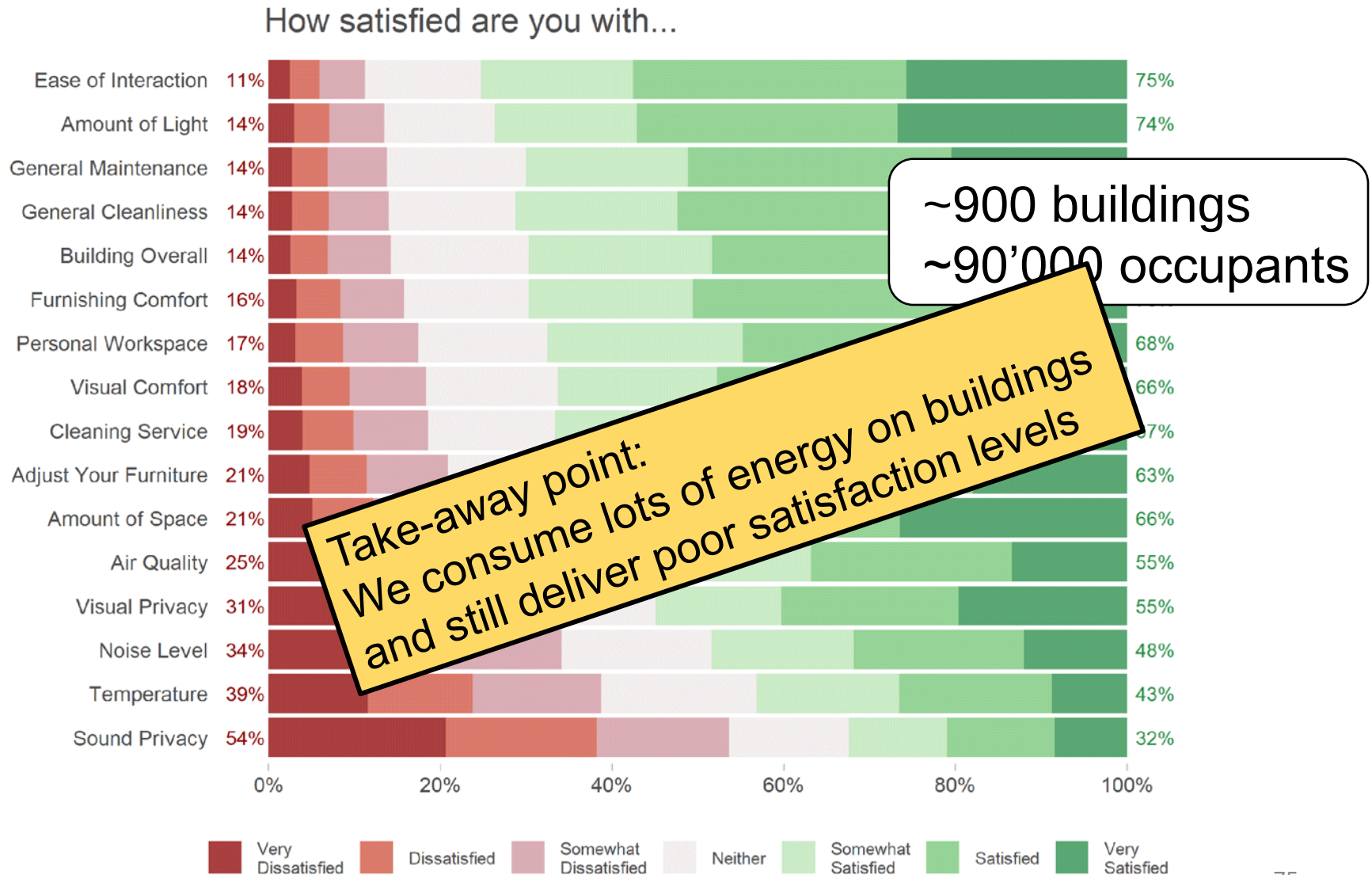


Comfort and buildings

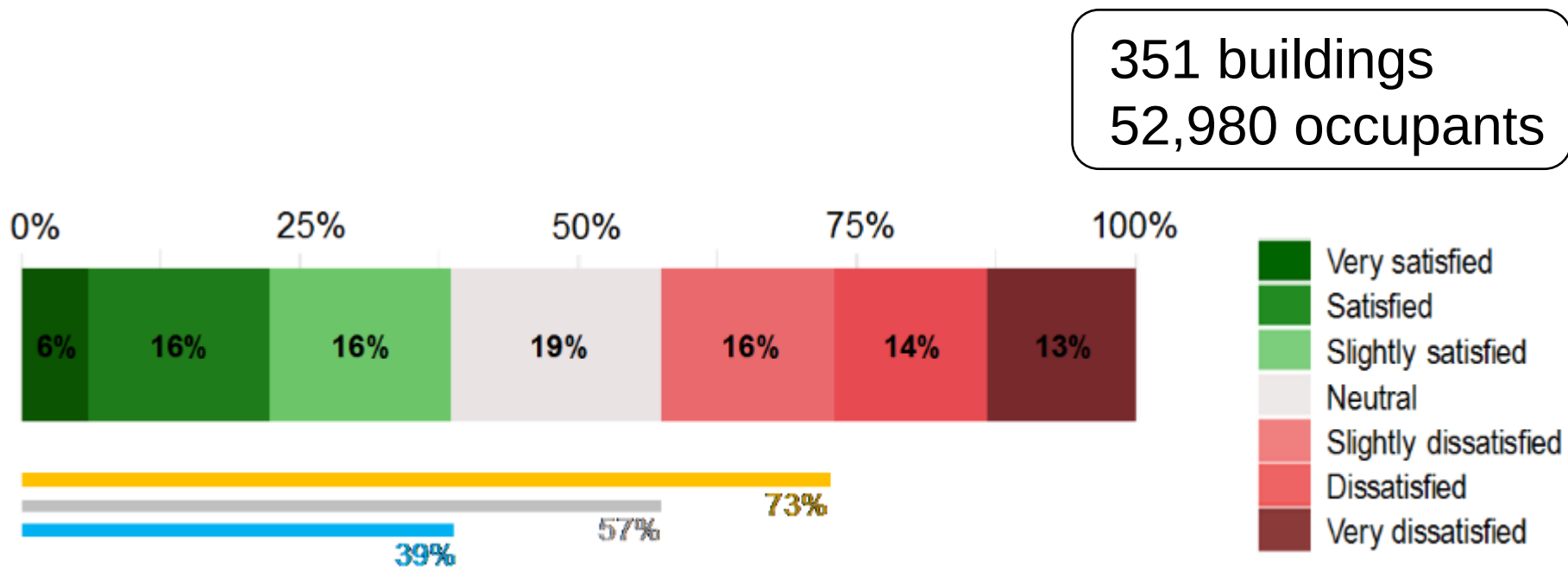
Good design may not be sufficient



Occupant satisfaction in buildings



Air temperature satisfaction in offices

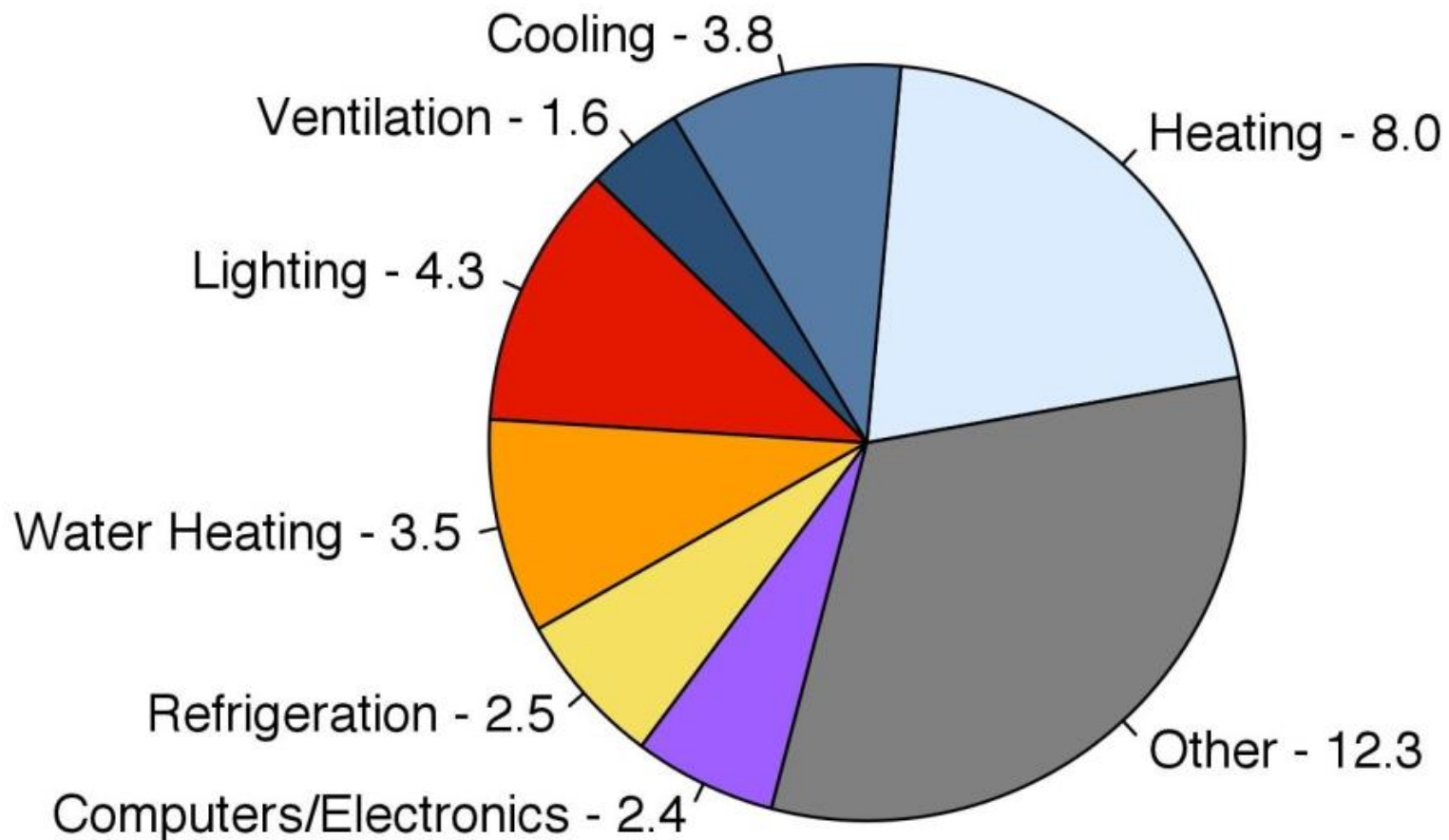


(Source: Karman et al 2018, Windsor Conference)

- ~40% of occupants are dissatisfied with air temperature
- ~40% of occupants are satisfied
- So we consume so much energy on buildings and still delivering such a poor performance -- what the heck can we do about it?

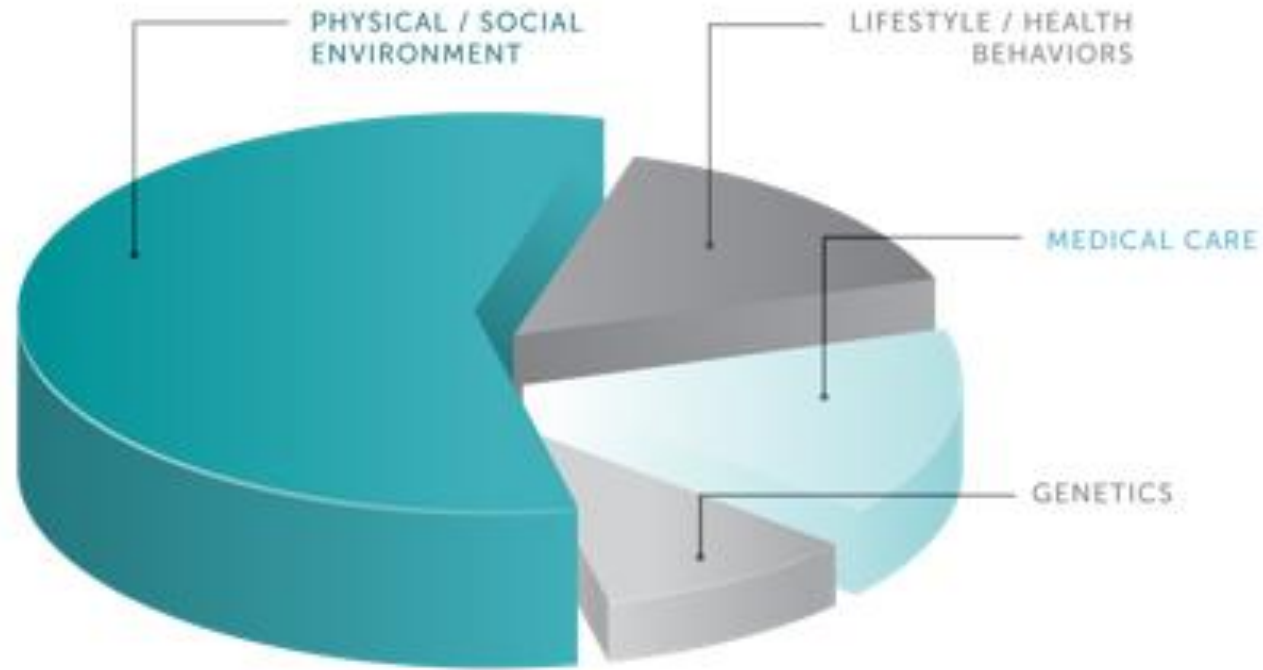
Influence of indoor environment: **Energy**

2014 Residential and commercial building primary energy use (%)



Influence of indoor environment: **Health**

**WHAT
DETERMINES
THE STATE
OF HEALTH?**



**...BUT WHAT
ABOUT THE ROLE
OF BUILDINGS?**

Role of indoor environmental quality (IEQ)?



Thermal comfort



Lighting



Indoor air quality



Acoustics

(Source: Barbara⁷⁹ Erwine)

IEQ, Stress mechanisms, and Human Health



**ACOUSTIC
QUALITY**



**AIR
QUALITY**



**LIGHTING
QUALITY**



**THERMAL
QUALITY**

STRESS MECHANISMS

Anti-stress

Circadian rhythm

Endocrine disruption

Oxidative stress

Inflammation, irritation

Cell changes/death

DISEASE / DISORDER

Depression

Obesity

Diabetes

Chronic resp. diseases

Cardiovascular diseases

Cancers

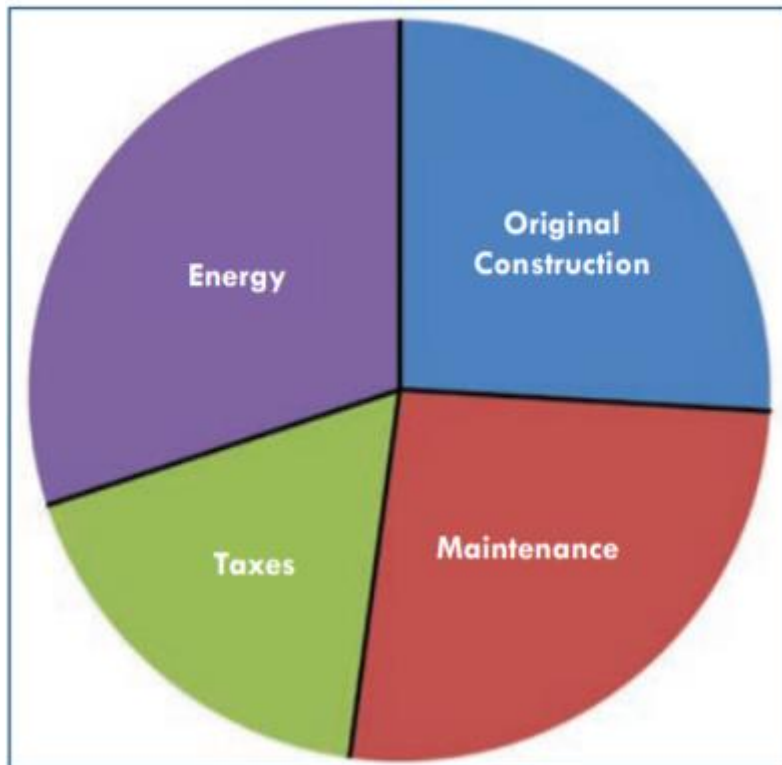
In class discussion...

Comfort and Health vs. Energy Use

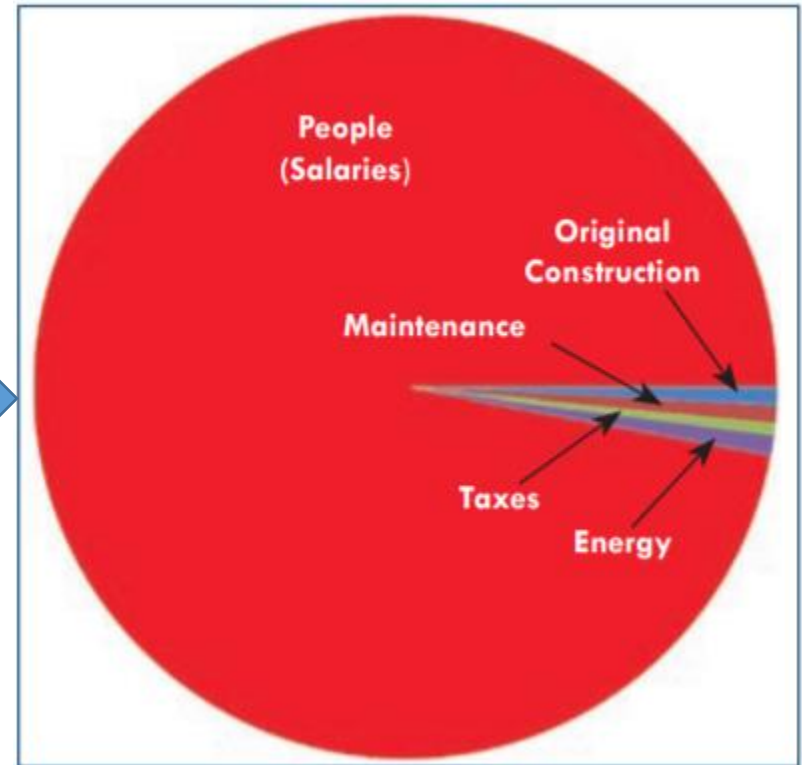
1. What do we focus on primarily?
2. What matters more?
3. Are they often in conflict or not?
4. What costs more (assume you are a business owner)?

Operating costs disentangled

Life-cycle building costs breakdown



Life-cycle building costs breakdown with people



- We can argue the numbers here, but not the orders of magnitude
- Reducing energy by 30% is negligible compared to the cost of people
- A net zero energy building (if possible) saves only 1% of salary costs!

Business case: Energy vs Health

Baseline Company Assumptions	
Number of Employees	40
Average Salary	CHF 75'000
Salaries as Percentage of Revenue	50%

	Baseline (CHF)	% of Revenue
Revenue	6'000'000	
Salaries	3'000'000	50
Rent	300'000	5
Utilities (energy)	30'000	0.5
Other expenses	1'000'000	16.7
Net income before taxes	1'670'000	27.8
Taxes (30%)	501'000	8.4
Net income after taxes	1'169'000	19.5

Business case: Energy vs Health

What if 1: Company invests in technology that will cause substantial energy savings of 20% (20% savings in utility bill)

(CHF)	Baseline	Intervention	Baseline + savings
Revenue	6'000'000		6'000'000
Salaries	3'000'000		3'000'000
Rent	300'000		300'000
Utilities (energy)	30'000	-20% (6'000 CHF)	24'000
Other expenses	1'000'000		1'000'000
Net income before taxes	1'670'000		1'676'000
Taxes (30%)	501'000		502'800
Net income after taxes	1'169'000		1'173'200
Change			0.36%

Conclusion: Change is <1%. High effort for small \$\$ savings

Business case: Energy vs Health

What if 2: Company invests in technology (increased ventilation rates) that will cause health improvement by having 2 fewer sick days per year (1% savings in salary) and productivity boost by 2%

(CHF)	Baseline	Intervention	Baseline + savings
Revenue	6'000'000	+2% (120'000 CHF)	6'120'000
Salaries	3'000'000	-1% (30'000 CHF)	2'970'000
Rent	300'000		300'000
Utilities (energy)	30'000	+1'600 CHF	31'600
Other expenses	1'000'000		1'000'000
Net income before taxes	1'670'000		1'818'400
Taxes (30%)	501'000		545'520
Net income after taxes	1'169'000		1'272'880
Change			8.9%

Conclusion: Substantial increase in revenue with simple strategy

IEQ impact on businesses & people: **Huge!**

Organizational outcomes



- Productivity loss
- Absenteeism
- Presenteeism (working while sick)
- Staff turnover/retention
- Revenue
- Medical costs
- Medical complaints
- Physical complaints
- Task efficiency & deadlines met, etc.

Comfort and health



- Headaches
- Eye strain/damage
- Dry throat and runny nose
- Skin irritation
- Infections
- Fatigue
- Seasonal Affective Disorder
- Asthma & breathing disorders
- Stress & depression
- Other serious disorders, including cardio-vascular, etc.

Value of comfort and well-being to real estate



Paradigm shift from system-centric environmental design
to human-centric approach

New principles reflected in dozen of languages



Where are we now?

High market penetration with exponential increase

Currently - Thousands of ongoing projects from 200 certification programs around the world



After-class thinking...



•

Do a detailed bullet point list of the tasks that you would do to assess the energy and indoor environmental quality of EPFL building

•

Describe a strategy that may simultaneously increase energy efficiency and indoor environmental quality for that building

•

Describe which steps would be needed to assess if the strategy is effective or not

Summary of key concepts learnt today

- 
- Human activity is the cause of increased GHG concentrations, and therefore climate crisis.
 - Energy use in buildings has the strongest (but not sole) influence on our climate.
 - Reducing building carbon footprint requires setting priorities and hierarchy of actions.
 - Buildings shape human health, comfort and well-being in substantial ways, many which have been neglected by people who commission, design, manage and use buildings.
 - Investment in healthy buildings presents a better business model relative to investment in energy saving measures. However, both are extremely important!
 - There is a strong nexus between building energy use and indoor environmental quality. We will explore this in the first half of the semester.

Next time lecture on thermal comfort & energy

Thermal comfort & energy

- Thermal comfort (overview)
- Overheating of buildings
- Thermal comfort & energy efficiency
- Quiz



Note:

For those who want to get a quick brush-up on the fundamental concepts of energy and power units, heat transfer in buildings and psychrometric, please check out extra slides available on Moodle (within Week 01)